AD 283 115

WIDE ANGLE PERISCOPE SYSTEM
DESIGN AND PROTOTYPE EVALUATION

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I. ABSTRACT

A new concept for a wide angle periscope suitable for installation in the cockpit of an aircraft was investigated. The periscope was to have a horizontal view of 180° with a $\pm 15^{\circ}$ vertical view and be capable of rapid closure.

The system comprises a series of reflecting elliptical surfaces of revolution arranged about a vertical axis. The observer is located at the center of the lowest surface, and is essentially surrounded by a view of the outside scene having normal intensity.

Design studies of the system were made with regard to scaling, surface precision, eye position sensitivity, distortion and focus.

Fabrication techniques and materials were examined and two sets of surfaces manufactured to obtain further answers to questions raised or left unanswered by the analytical approach.

The result of the design studies and prototype evaluations was to point out the extreme sensitivity to eye position for a system of this size and the need for optically precise surfaces which were unobtainable by the approach used.

II. INTRODUCTION

This report covers the design, development and fabrication activities concerned with a wide field of view periscope device intended for use in aircraft. The work on this program was accomplished under Bureau of Naval Weapons Contract NOw 61-0348-c.

The periscopic technique provides an undistorted field of view up to 180 degrees. The system utilizes a large portion of the enclosure surface surrounding the operator's head as a viewing screen. At the same time, the installation would allow the simultaneous use of this area for instruments and indicators.

The device consists of a number of ellipsoids of revolution oriented along a vertical axis, each having a common focus with the succeeding surface. The operator, located inside of the last surface, observes the same scene he would see if his eye were actually at the top surface.

The program undertaken was divided into two phases. The first called for a mock-up of a device for installation in an A4D aircraft. This was to be approved by the Bureau of Naval Weapons prior to starting the second phase, consisting of the fabrication of a prototype system for flight test evaluation.

Early in the program, a number of difficulties were found to exist with the use of an A4D aircraft for flight test and a change to the A3D was made. Design studies were made to determine a suitable configuration and the required surfaces were manufactured.

Evaluation of the mock-up system pointed up several shortcomings. The system was very sensitive to pilot eye location and the quality of the metal surfaces used was in need of improvement. A review of the mock-up and the problems encountered was held with a Bureau of Naval Weapons representative, resulting in approval to continue with the program. A suitable device to locate the pilots eye was to be incorporated as well as a different technique for the manufacture of the surfaces.

The major effort of the second phase was put on the manufacture of the metal surfaces by an improved technique along with some additional studies of the focusing aspects of the system. In spite of the effort and care put into the surfaces, the results were not appreciably better than the original surfaces, leading to the conclusion that more sophisticated optical fabrication techniques were necessary.

The additional focus studies indicated some system focus problems which could not be fully evaluated because of the surface quality.

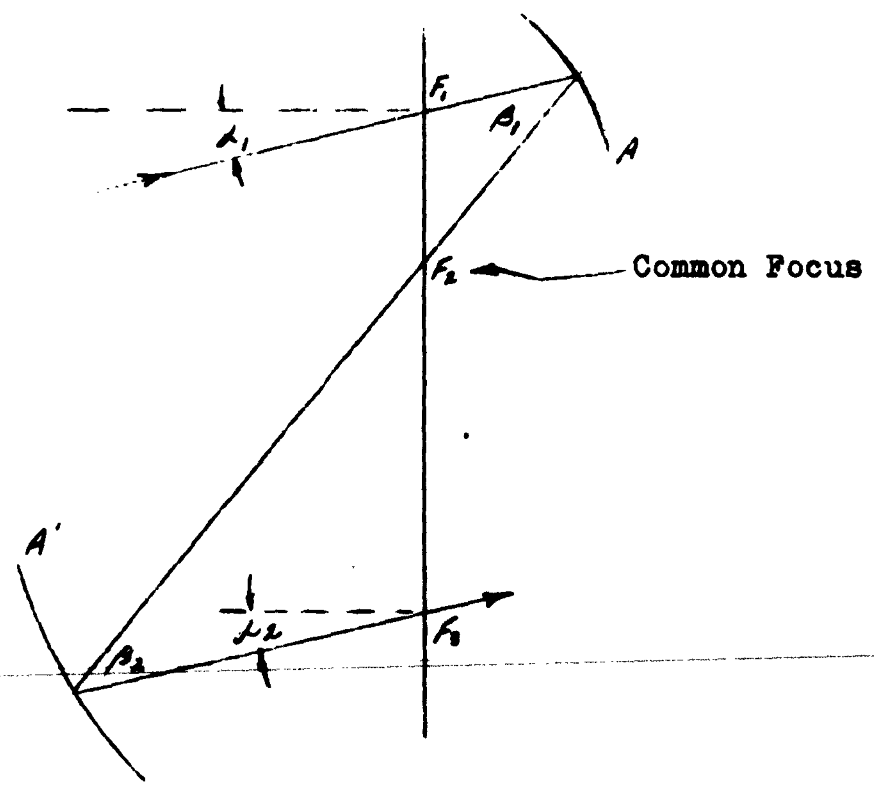
Termination of the program was recommended by the contractor as it was felt only the most sophisticated optical fabrication techniques would result in satisfactory surfaces. Such an approach was beyond this contractor's capability. This, along with the critical eye problem, raised the question of the advisability of further pursuit of the development effort.

III. SYSTEM DESCRIPTION

A. Geometry - Distortion

The geometry and distortion characteristics of the proposed device depend upon two fundamental properties of elliptical surfaces. If a ray of light passes through one focus of an ellipse, it will be reflected from the surface in such a direction that it will pass through the other focus. In addition, the slope of the curve, or surface, at any particular point is a function only of the eccentricity of the ellipse.

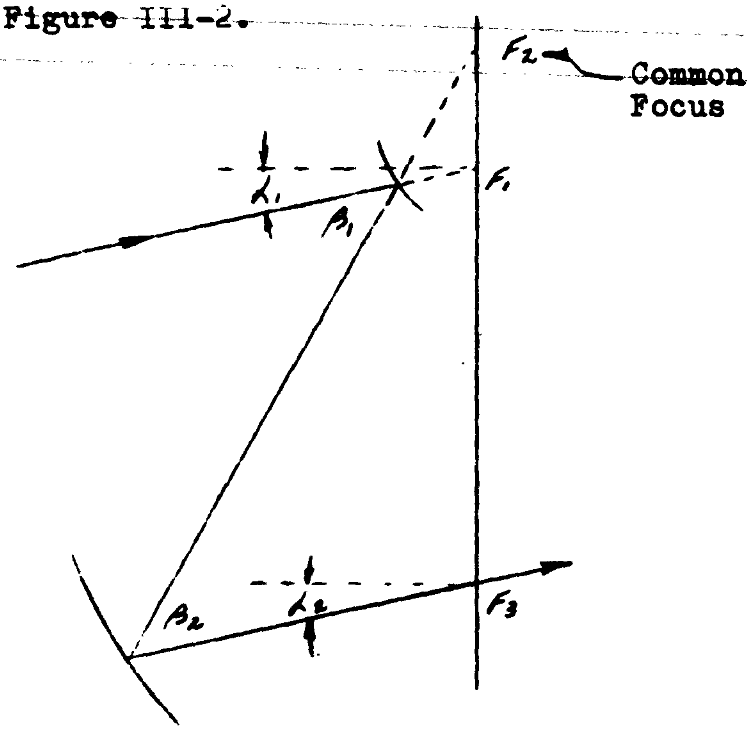
The application of these two principles is illustrated in Figure III-1, which shows two elliptical arcs which are oriented along a common axis. In addition, although they have different scales, both surfaces have the same eccentricity, and are positioned so that one of the foci of each ellipse is located at the common point F_2.



Basic Mirror Configuration - Inside Surfaces
Figure III-1

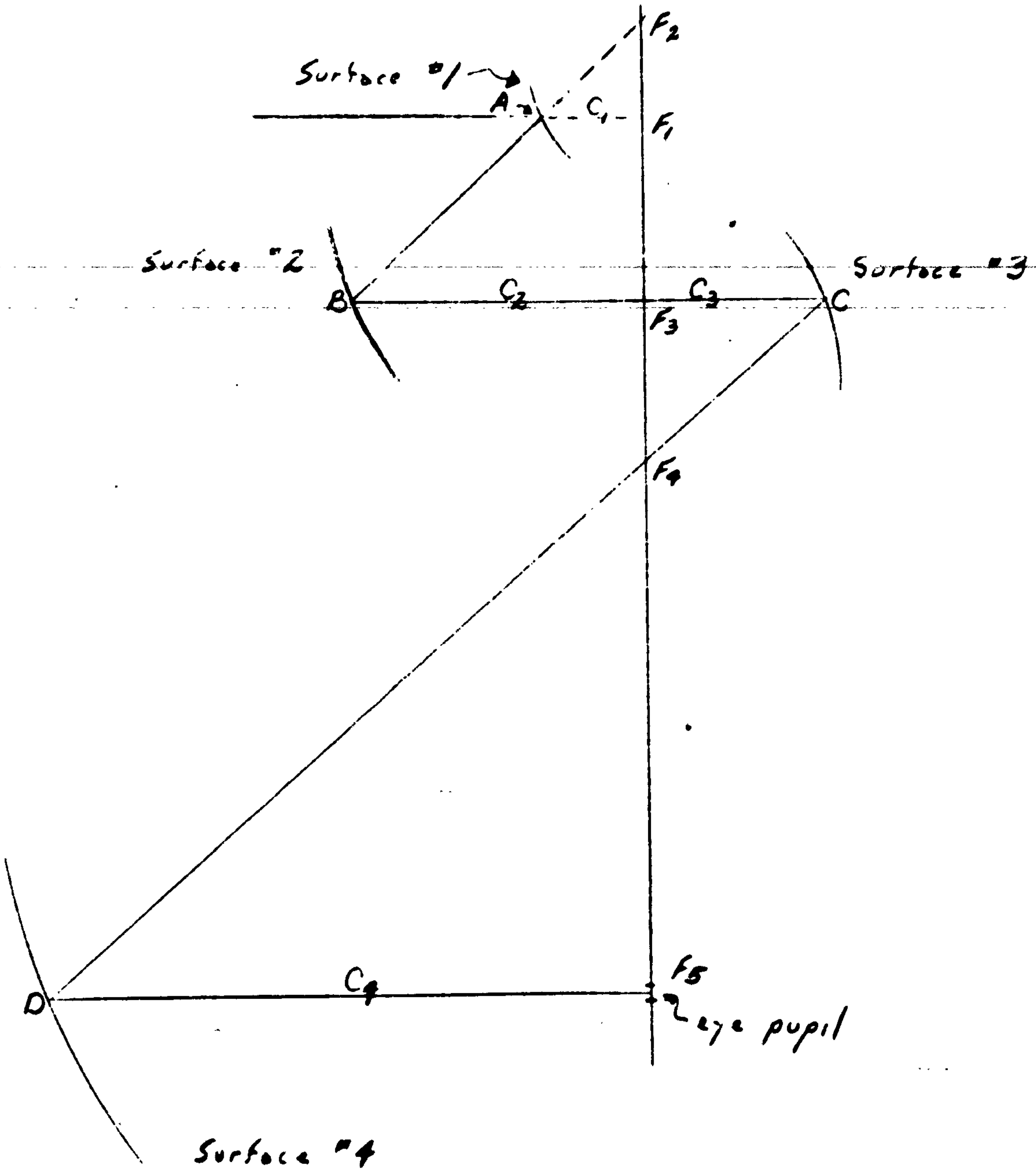
A ray of light passing through the focus F_1 of the top ellipse is reflected back through the common focus, and then through F_3. Since they have the same eccentricity, the surfaces at A and A' are parallel so that the angles B_1 and B_2 are equal. This means that the light ray approaches F_3 from the same direction that it approached F_1 and the system is distortion-free.

The same observations can be made for a pair of surfaces in which one outside face is used as illustrated in Figure III-2.



Basic Mirror Configuration - One Outside Surface
Figure III-2

It follows directly that additional pairs of surfaces can be stacked on the system, maintaining the same result. This is illustrated in Figure III-3, which shows the system actually proposed. As will be developed in the discussion of focusing, the additional pair of surfaces eliminates the need for a large refracting device in order to focus the presentation. This distortion-free vertical presentation can then be given any horizontal field of view desired simply by using the arcs of Figure III-3 to generate surfaces of revolution about the axis of the foci.

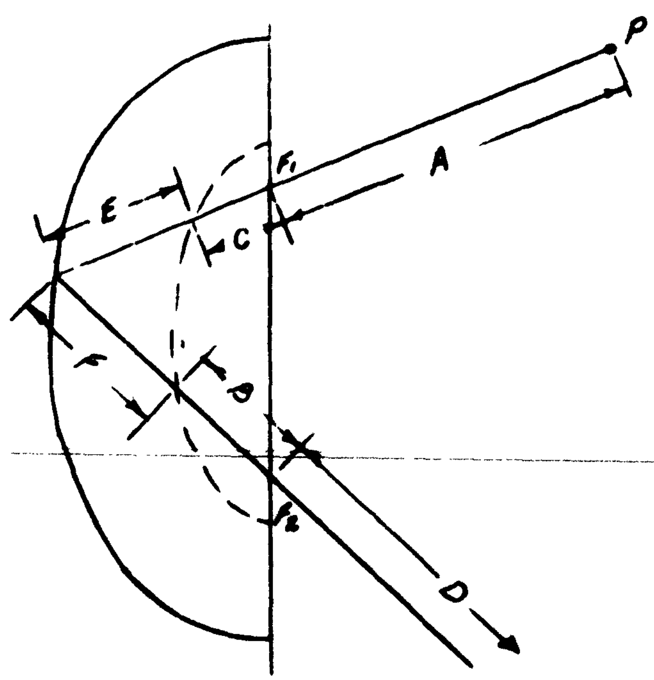


Periscope System - Foci and Surface Identification
Figure III-3

B. Focus

The exact focusing situation for a device of this nature depends upon the relative scale and eccentricity of the various surfaces. A number of general observations can be made, however, about the ability to focus the system by considering a few fundamental rules of the same nature as those applying to spherical surfaces.

These are illustrated by the sketch of Figure III-4, which shows a single ray of light from some object, (p), passing through the two foci, F_1 and F_2. The prime focus of the ellipse is located somewhere between the surface and the foci. If the object is located at A, anywhere between F_1 and infinity, it will be imaged at B, somewhere between the prime focus and F_2. If it is located at C, between F_1 and the prime focus, it will be imaged at D, between F_2 and infinity. If the object is at E, between the prime focus and the surface, it will be imaged to the left of the surface somewhere between the surface and infinity.



Object - Image Location for Elliptical Surfaces
Figure III-4

Finally, if the object is located to the left of the surface, it will be imaged at F, between the surface and the prime focus.

It is possible to consider the proposed system, and apply the general rules in examining the focus. Figure III-5 illustrates the top ellipsoid. All of the objects viewed through this surface are located outside of the surface between it and infinity. The resulting images can then be expected to be formed somewhere between the surface and its prime focus A. If the object distance is located more than approximately five times the physical size of the reflector, the image can be

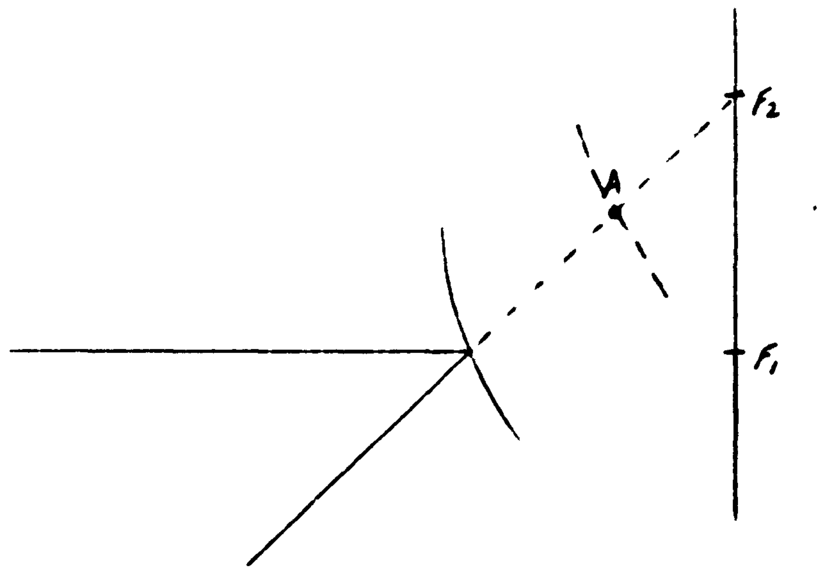


Image Location - First Surface
Figure III-5

considered to be located at the prime focus for all practical purposes. This image A then becomes the object for the second surface as illustrated in Figure III-6.

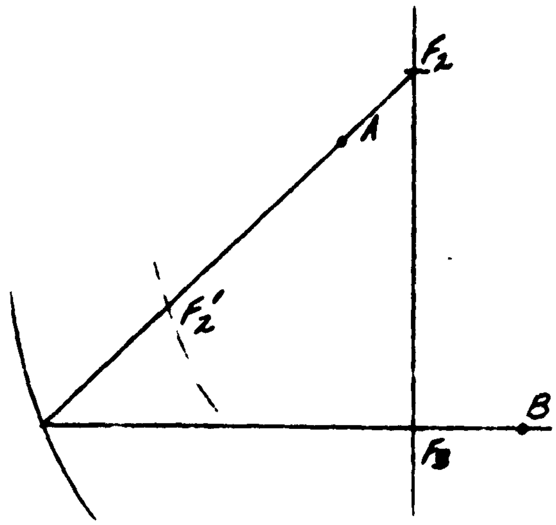


Image Location - Second Surface
Figure III-6

The prime focus of the second surface is located in the general area indicated by F_2'. Since the object A is located between the top focus and the prime focus, this surface will form the image on the other side of the second focus at the same location B as indicated.

Now, if the scale of the third surface is selected so that its prime focus F_3' falls outside of the object B, as illustrated in Figure III-7, the resulting image can be located anywhere on the left side of the system axis by relatively minor adjustments of the size of this surface.

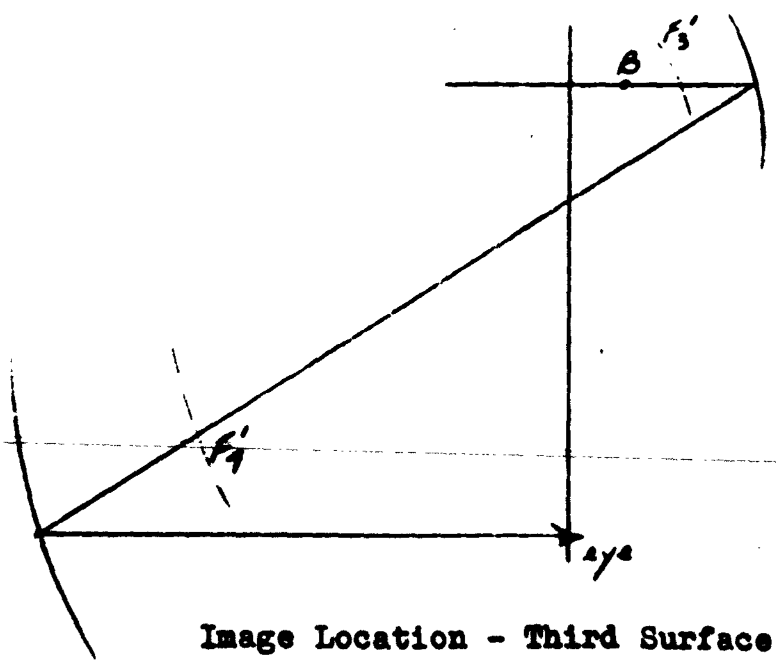


Image Location - Third Surface
Figure III-7

An optimum adjustment appears to be one which would image the object B at F_4', the prime focus of the bottom surface. The operator, located at the lower focus of the surface, would then see the entire scene focused at infinity, and would have essentially the same situation as a direct view with the naked eye.

C. <u>Image Intensity and Resolution</u>

Figure III-3 illustrates a vertical section of the system with the various foci located, and an exaggerated representation of the eye pupil at the bottom focus.

The fourth surface actually images the eye pupil at F_4. Similarly, the third surface reproduces an image at F_3, the second at F_2, and the top surface produces an image at F_1. The observer located at F_5 then actually sees the same scene that he would observe directly if his eye were located at F_1. The ratio of the image size at F_4 compared to the eye pupil itself is equal to

$$M = \frac{F_4 D}{F_5 D}$$

or the ratio of the distance from the foci to the surface. Similarly, the ratio of the image size at F_1 to the pupil size at F_5 can be expressed as

$$M = \left(\frac{F_4 D}{F_5 D}\right)\left(\frac{F_3 C}{F_4 C}\right)\left(\frac{F_2 B}{F_3 B}\right)\left(\frac{F_1 A}{F_2 A}\right)$$

However, since surfaces 1 and 2 have the same eccentricity,

$$\frac{F_2 B}{F_3 B} = \frac{F_2 A}{F_1 A}$$

and similarly,

$$\frac{F_4 D}{F_5 D} = \frac{F_4 C}{F_3 C}$$

the eye pupil is imaged at F_1 with a magnification of unity. This means that the intensity of the scene which the observer views is exactly the same as the direct view from F_1, except for minor losses due to the reflectivity of the surfaces. No significant reduction in intensity is therefore expected.

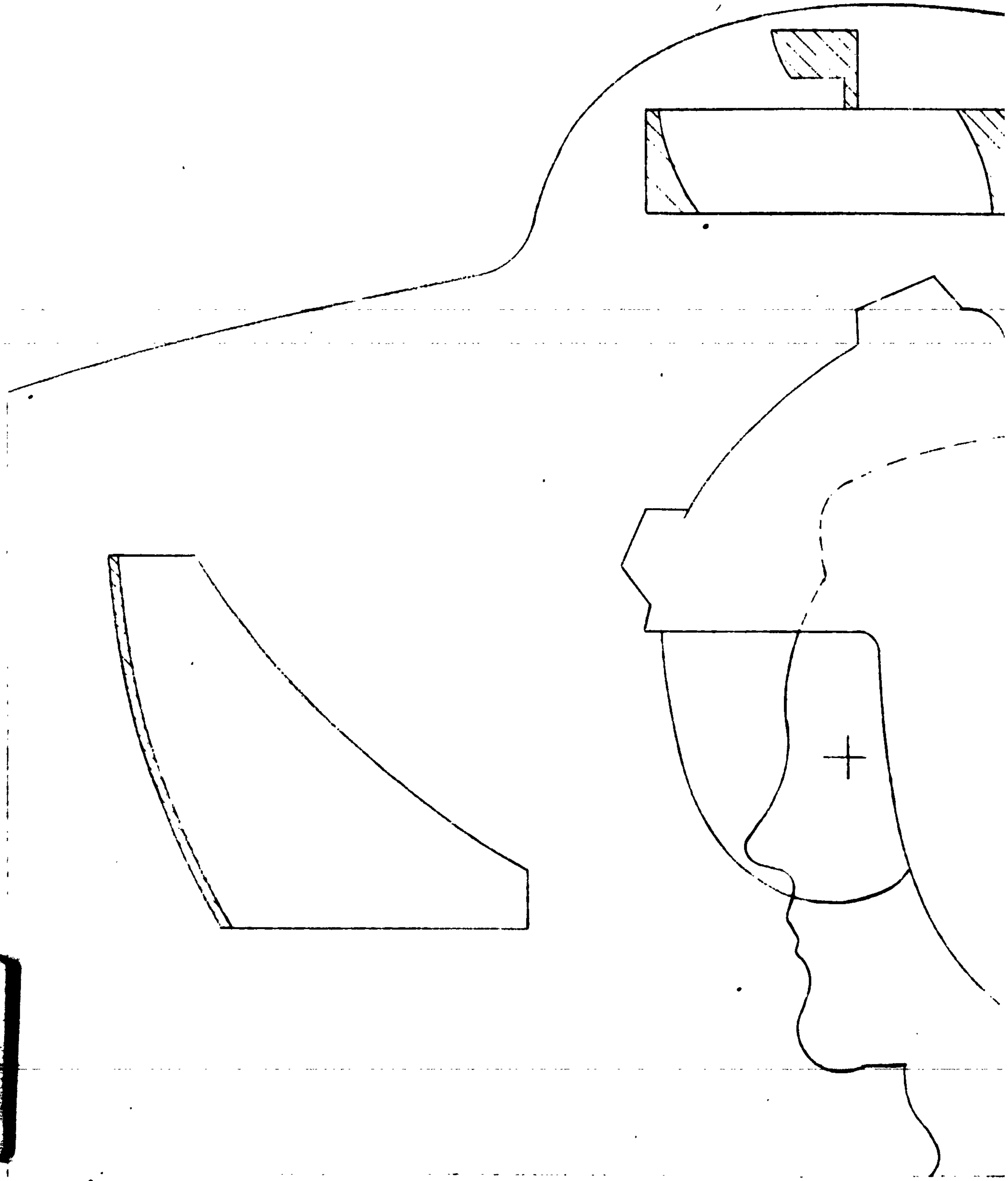
Similarly, the resolving power of the system is a function of its smallest stop. As shown in the discussion of focus, the eye pupil is the smallest stop in the system by a considerable factor, and therefore the basic resolving capability can be expected to be the same as for the naked eye.

IV. PHYSICAL LIMITATIONS IMPOSED BY THE AIRCRAFT COCKPIT

The initial intent of the program was to build a periscope for feasibility studies with the A4D aircraft. This was then the main factor in determining the overall size of the system and therefore the size of the individual surfaces.

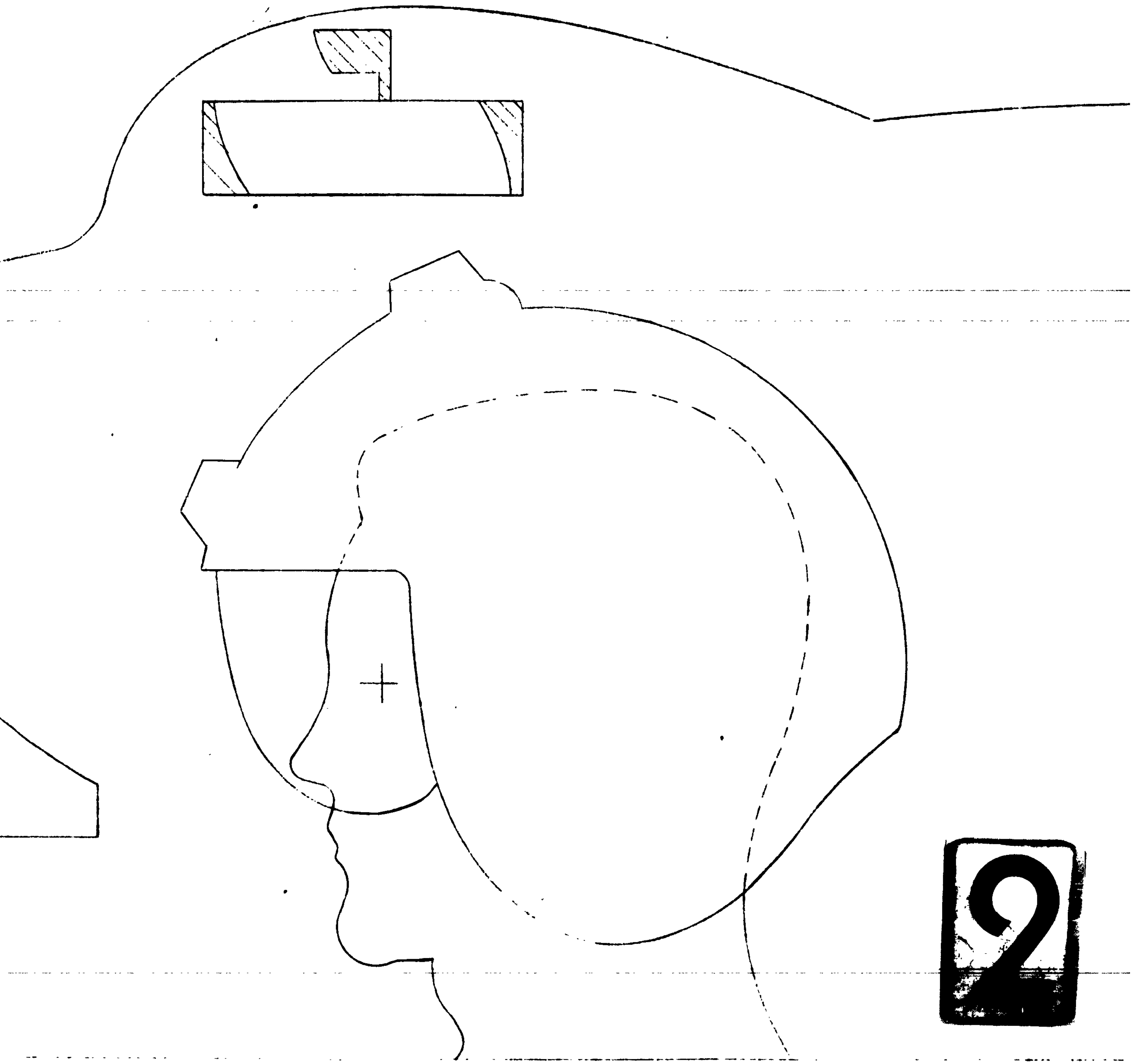
The proposed system has the pilots eye at one focus of the large surface with the other focus vertically above the eye. See Figure IV-1. With only a little over thirteen inches between the pilot's eye and the compass ahead of him, the distance from the surface of the mirror to his eye could not be greater than this. Another limitation is imposed by the size of the pilot's helmet and the canopy location above the head. To prevent the helmet from blocking the rays to the large surface, its second foci must be located above the top of the helmet with a minimum foci separation of about seven inches. This puts the foci within an inch of the canopy, making it impossible to add the remaining three surfaces while remaining wholly within the cockpit. A small bubble added to the canopy was proposed to cover the necessary protrusion.

Using eye to surface distances C_4 of 10, 11 and 13 inches and a foci separation of 7 inches, the three surfaces were located inside of the cockpit and the intersection of the surfaces with the canopy determined. To prevent interference, much of the upper section of the surfaces except for a narrow forward view had to be removed. Figure IV-2 is a plot of the vertical view versus the horizontal angle measured from the ahead position. For the largest surface $C_4 = 13$ inches, a $\pm 15^{\circ}$ vertical view is obtainable for only $\pm 7^{\circ}$ from the ahead position. This increases to $\pm 26^{\circ}$ for the ten inch surface. A further increase would be obtained if C_4 were reduced below ten inches with several major disadvantages. The



PERISCOPE INSTALLATION
A4D COCKPIT
SCALE: ½" = 1"

FIG. IV-1



ATION

FIG. IV-1

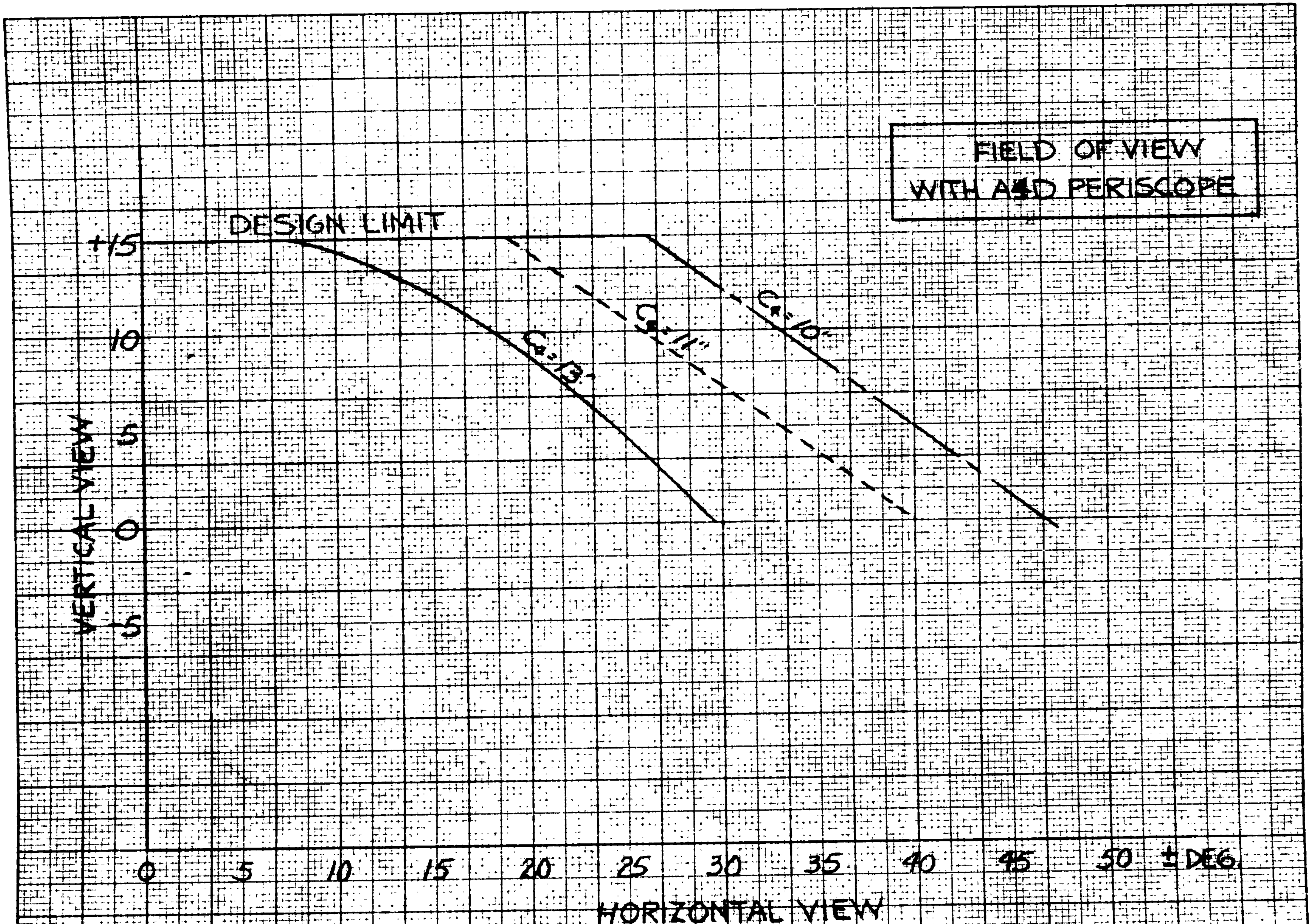

FIELD OF VIEW
WITH A&D PERISCOPE
DESIGN LIMIT
+15
10
5
0
-5
VERTICAL VIEW
0
5
10
15
20
25
30
35
40
45
50
± DEG.
HORIZONTAL VIEW

FIG. IV-2

distance between foci would have to be increased to prevent helmet blocking and the effect of eye motion to be discussed later would be increased.

Because of the objection to the protrusion, necessary modifications of the canopy, and the interference with the cockpit black out screen, a change to the A3D aircraft was made. Examination of the cockpit drawing of this aircraft, Figure V-3, showed it to be much more suited to the proposed periscope. A large mirror with C_4 of ten inches would fit wholly within the cockpit with no interference, allowing a full 180° field of view. Increasing C_4 much beyond the ten inches would again decrease the horizontal view in the upward direction because of canopy interference.

In the vertical direction, there is approximately 11.5 inches between the pilot's eye and a structural frame above his head. Using a foci distance of 7 inches for the fourth surface would allow about 4.5 inches for the remaining surfaces. The entire periscope may be kept within the cockpit and the proposed black out screen.

The view as seen by the pilot, assuming a projected eye position 10 inches above his normal eye position, is shown in Figure IV-4. A full 180° field is obtained with only a small blind spot to the right and down 7°, which is present due to a canopy structural member.

The following studies, mock-up and prototype systems, were based upon the preceding limitations.

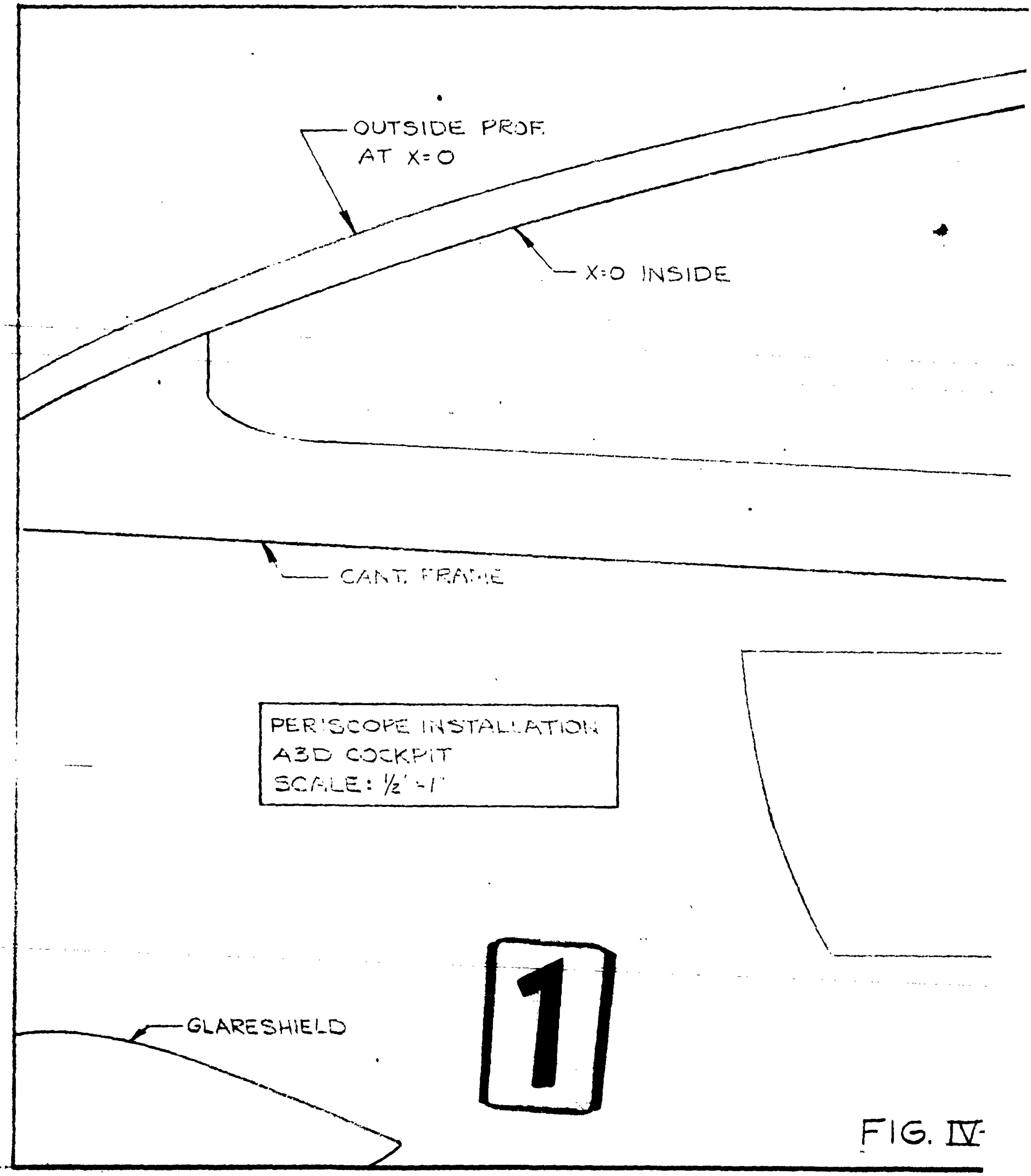

OUTSIDE PROF.
AT X=O
X=O INSIDE
CANT. FRAME
PERISCOPE INSTALLATION
A3D COCKPIT
SCALE: ½"=1"
GLARESHIELD
1

FIG. IV-

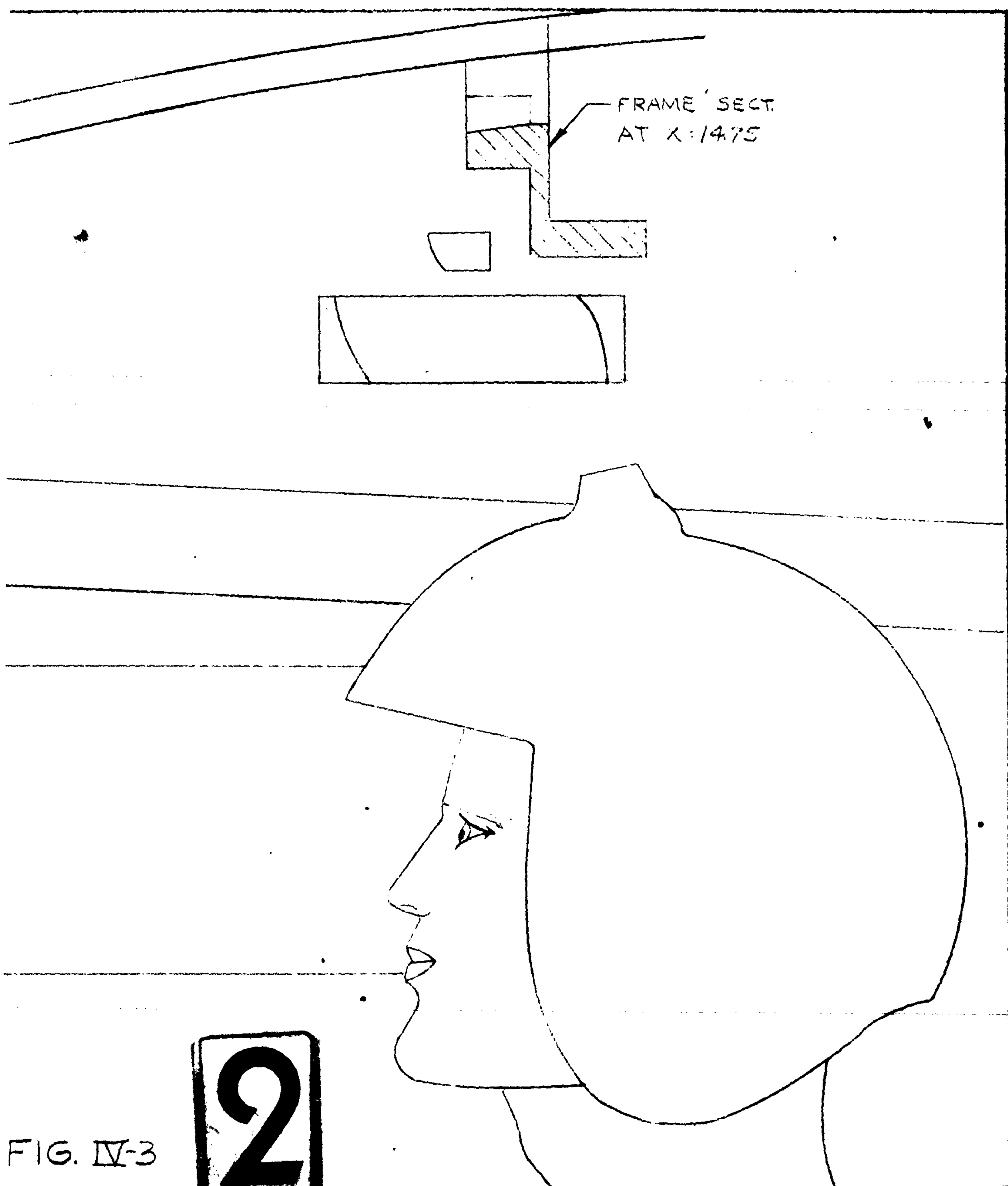
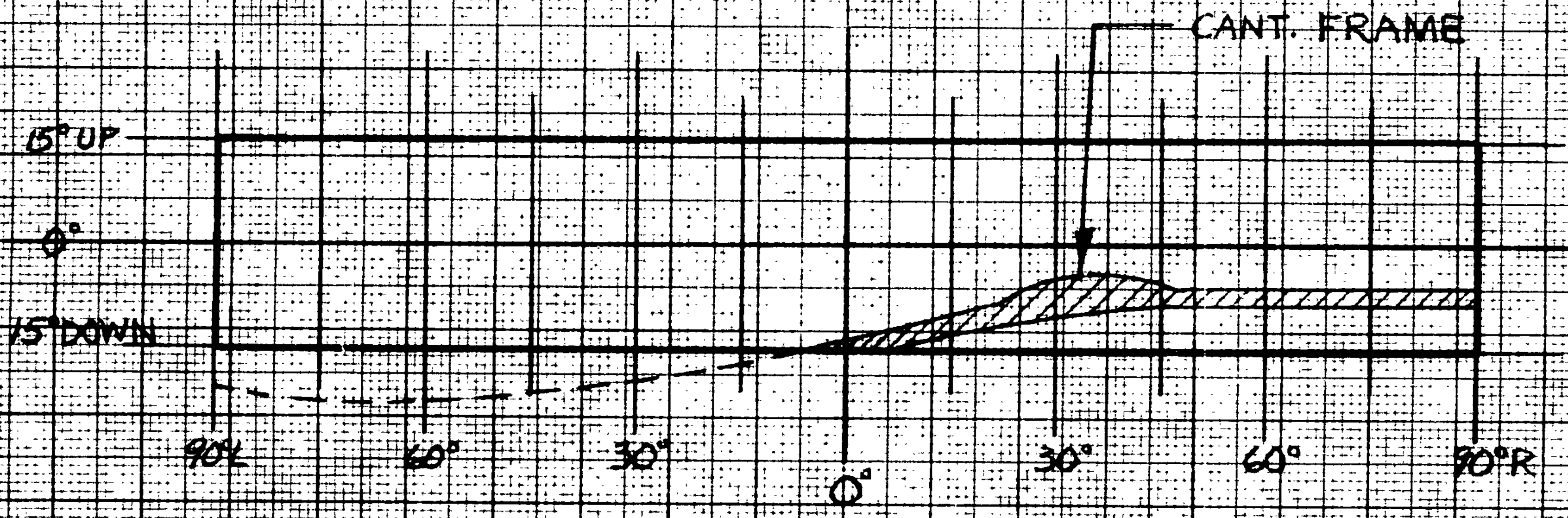


FIG. IV-3

2



FIELD OF VIEW THRU PERISCOPE
A3D COCKPIT

FIG. IV-4

V. EFFECT OF SURFACE SCALING AND ECCENTRICITY

While the cockpit does much to determine the overall size of the system, the scaling and eccentricity of the surfaces does enter the picture. In general, large surfaces are desirable to decrease the effect of eye motion. Surfaces with low eccentricity give more nearly spherical surfaces which could simplify the manufacturing problems. A number of possible configurations were derived and compared to each other to determine the effect of changing these parameters of the system.

The individual surfaces can be described by knowing the horizontal distance from a foci to the surface given the designation C and the distance between foci $F_a - F_b$. (See Figure III-3.) Holding C while increasing the distance between foci, increases the eccentricity of the surface while increasing both and keeping their ratio fixed increases the scaling.

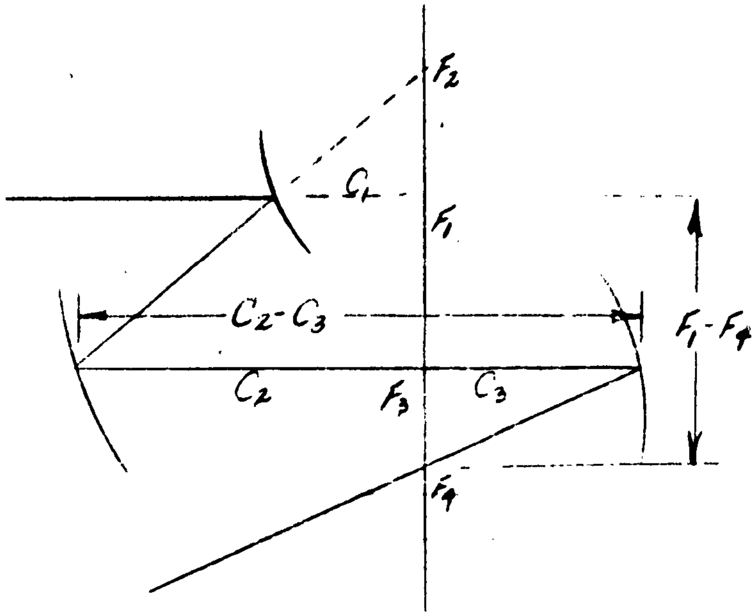
For the systems to be derived, the scale and eccentricity, and therefore the C and $F_a - F_b$ values were assigned for the first and fourth surface. This, in turn, fixes the eccentricity, but not the scale of the second and third surface. The second surface was kept as small as possible while allowing a 15^o down view, and the third surface was chosen to focus the horizontal incoming ray. Appendix A outlines the method of obtaining the unassigned perimeters.

Tabulated in Table V-1 are the values of C and F-F for the four surfaces of each system. The assigned values are shown in columns 1 thru 4, while columns 5 thru 8 give the resulting calculated values. A measure of the diameter and height of the upper three surfaces is the sum C_2 and C_3 and the distance between F_1 and F_4. (See Figure V-1.) These are given in columns 9 and 10.

TABLE V-1

Systems Configuration

	ASSIGNED VALUES				CALCULATED VALUES					
	1	2	3	4	5	6	7	8	9	10
System	C_1	F_1-F_2	C_4	F_4-F_5	C_2	F_1-F_3	C_3	F_3-F_4	C_2-C_3	F_1-F_4
1	2	1.5	13	7	8.0	4.5	3.0	1.6	11.0	6.1
2	2	2.0	13	7	5.0	3.0	3.2	1.7	8.2	4.7
3	2	3.0	13	7	3.7	2.5	4.2	2.2	7.9	4.7
4	2	4.0	13	7	3.0	2.0	4.6	2.5	7.6	4.5
5	2	2.0	11	7	5.0	3.0	4.2	2.8	9.2	5.8
6	2	2.0	10	7	5.0	3.0	4.3	3.0	9.3	6.0
7	2	2.0	7	8	5.0	3.0	6.1	6.9	11.1	9.9
8	1	1.0	13	7	2.5	1.5	1.8	1.0	4.3	2.5
9	1	1.0	10	7	2.5	1.5	1.9	1.35	4.4	2.85
10	2	4.0	13	7	5.0	5.0	2.4	1.35	7.4	6.35
11	2	4.0	13	7	6.5	9.0	1.3	.7	7.8	9.7



Size Approximation - Upper Surfaces
Figure V-1

The first four systems in the table have the same value of C_1, and the same fourth surface, but an increasing eccentricity of the upper surface. As the distance between F_1 and F_2 increases, the incoming rays are reflected down at a steeper angle, allowing the second surface to be brought closer to the vertical axis without blocking the lower portion of the incoming picture. This, in turn, moves the image formed by the second surface further from the axis requiring a larger third surface. Looking at the last two columns, both the height and the diameter of the upper surfaces decrease as the eccentricity increases, but at a decreasing rate. Little is gained in systems 3 and 4 over 2.

The effect of decreasing the C_4 distance, which increases the eccentricity of surfaces three and four, is shown by comparing system 2 with systems 5, 6 and 7. As the fourth surface moves toward the axis, the third surface must move away from the axis to maintain a focused image. Since the first two surfaces remain unchanged, the upper three surfaces increase in height and diameter with a decrease in C_4. The overall size is also affected by the fact that for a C_4 of less than ten inches, the distance between F_4 and F_5 must increase to prevent the pilot's head from interfering.

The effect of using a larger value of C_2 than necessary is shown by comparing system 4 with systems 10 and 11. Using the larger surface while keeping the same eccentricity increases the $F_1 - F_3$ distance as well, resulting in an increase in system height.

In all of the systems considered thus far, the system height above F_4 has been greater than 4.5 inches. To decrease the size below this value, it is necessary to reduce the scale of the upper surfaces. Systems 8 and 9 are similar to 2 and 6 respectively, with the scale of the upper surfaces cut in half. An additional size decrease is obtained as the image formed by the second surface moves toward the axis, decreasing slightly the scale of the third surface. A height above F_4 of 2.5 inches is obtained for system 8 with a slightly higher value of 2.85 inches for system 9. Because of the increased field of view obtained when using a ten inch surface, system 9 was chosen for the mock-up and prototype systems.

In addition to showing the effect of scaling and eccentricity on system size, some of the systems derived herein were used for studying the effects of spherical surface approximations and off-center eye locations. This information is presented in the succeeding sections.

VI. EFFECT OF SPHERICAL SURFACES

The system thus far described was made up of surfaces formed by revolving elliptical arcs about the major axis of the ellipse. From a manufacturing point of view, it would be much simpler to use spherical sections as an approximation of the elliptical section and for this reason several spherical approximations were investigated.

A. One possibility giving spherical surfaces, is to change the curvature of the ellipse slightly by taking as the center of curvature the intersection of the true radii to point P (Figure V-1) and the major axis. Revolving this surface about the major axis would give a section of a sphere. The intersection of the surfaces with any vertical plane through the major axis would be identical.

A ray from one foci to point P would be reflected through the other foci for either surface as the slope of both is the same at point P. For any other ray to the surfaces from the foci, the result would be different with only the correct surface reflecting the ray to the second foci. The smaller the eccentricity, the closer the ellipse would be to a sphere and the less the resulting error. Figure VI-1, Curve 2 and F_2' show the result of the approximation as compared to the correct curvature of Curve 1 and foci location F_2.

Using this approximation for all four surfaces would give results similar to Figure VI-2 where this was done for system 2. The error, introduced by the fourth surface when looking down 15°, was increased as ~~the ray was reflected through the system so that the~~ object seen by the eye was actually 48° above the imaged eye.

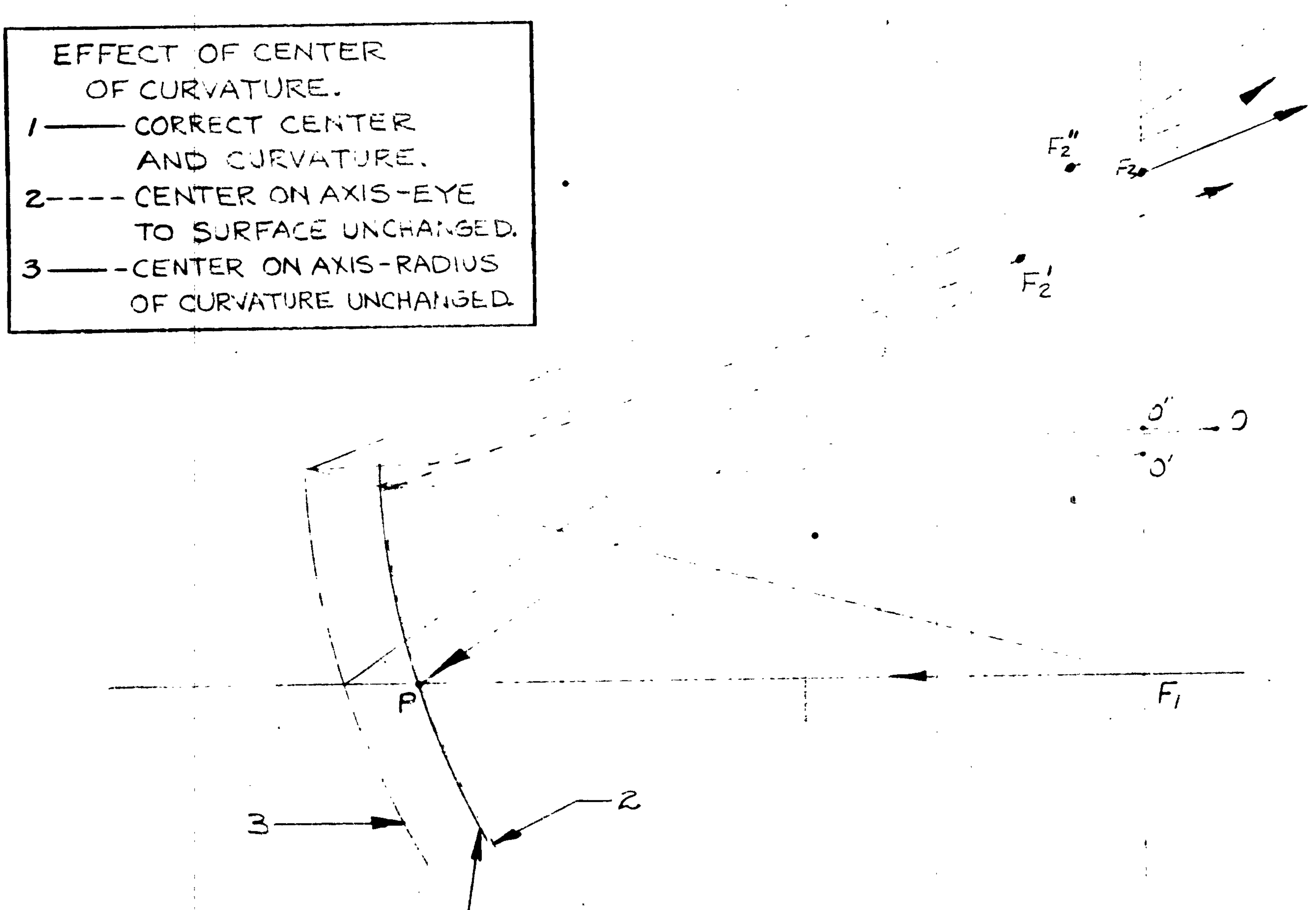
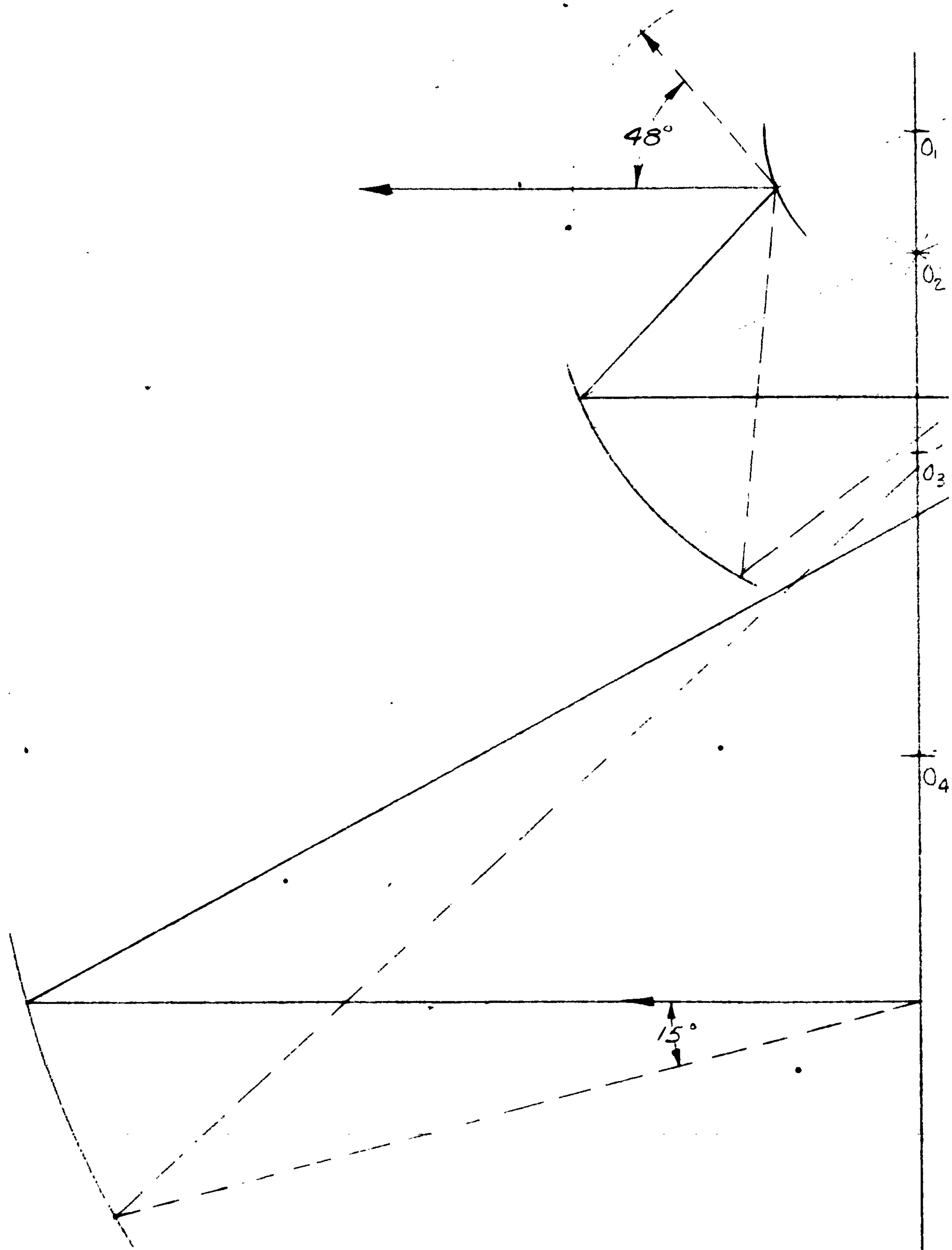

EFFECT OF CENTER
OF CURVATURE.
1 —— CORRECT CENTER
AND CURVATURE.
2 - - - - CENTER ON AXIS-EYE
TO SURFACE UNCHANGED.
3 —— - CENTER ON AXIS-RADIUS
OF CURVATURE UNCHANGED.
F_2''
F_3
F_2'
O''
O
O'
P
F_1
1
2
3

FIG. VI-1



1

FIG. VI-2

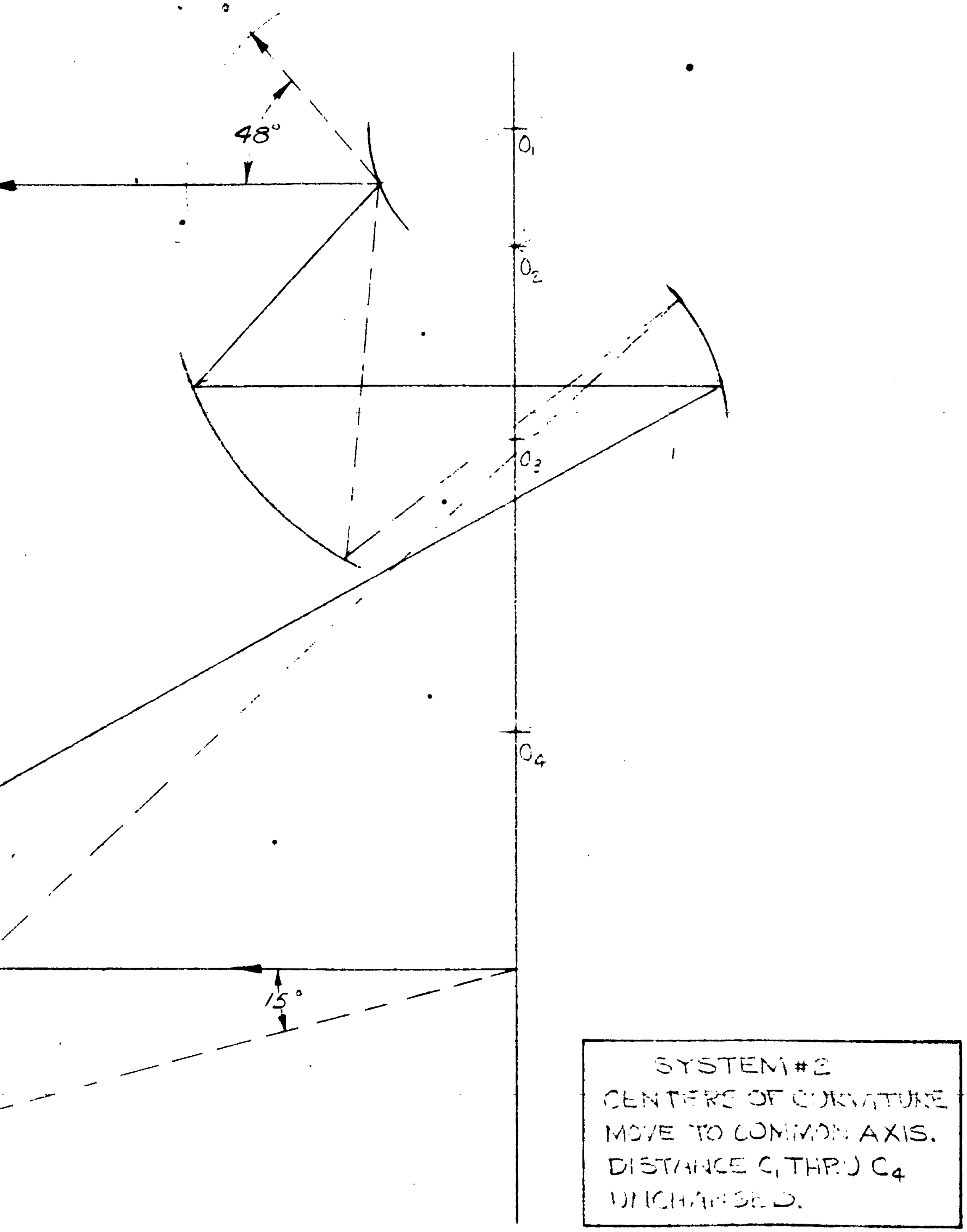
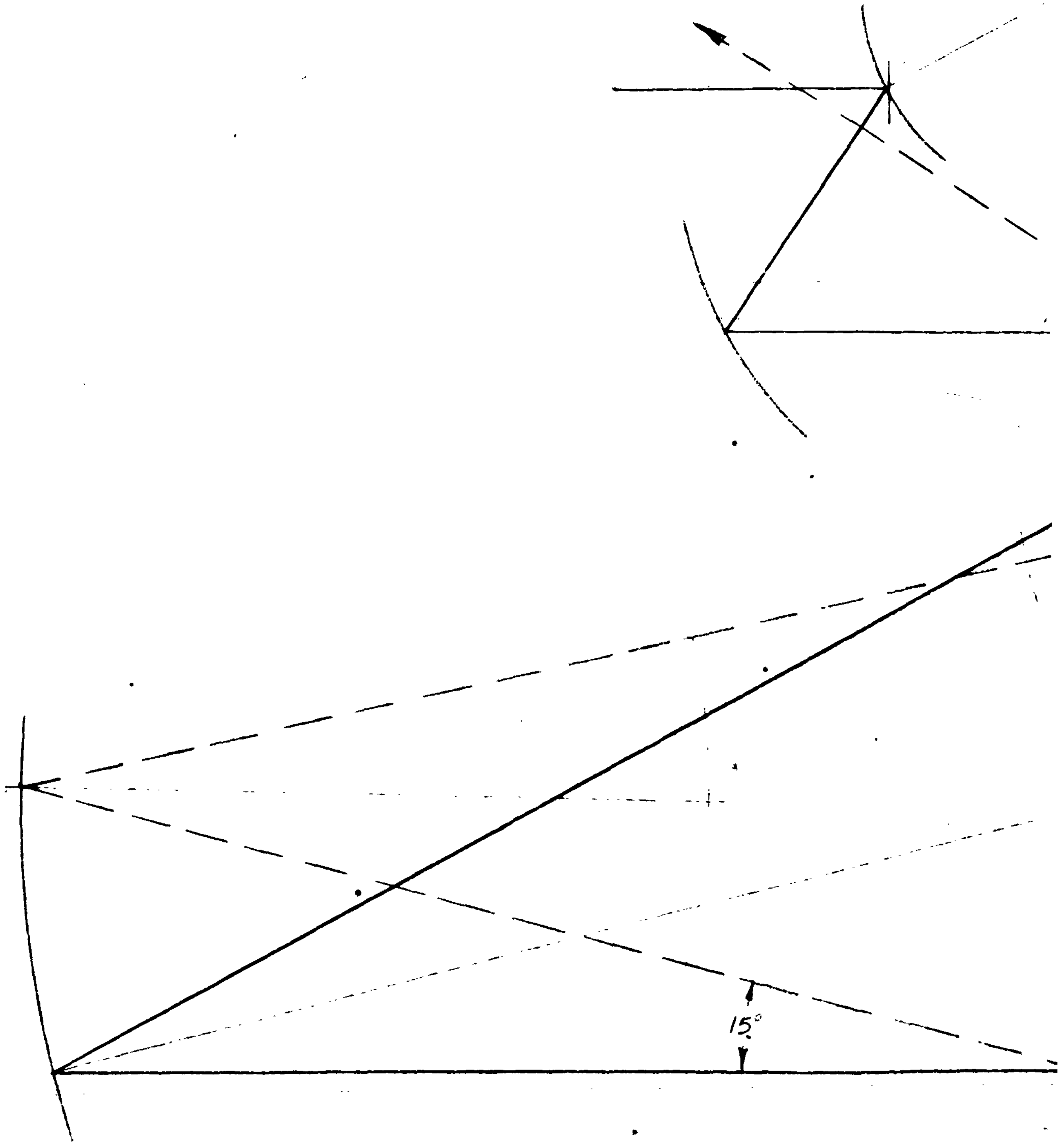

48°
O_1
O_2
O_3
O_4
15°
SYSTEM #2
CENTERS OF CURVATURE
MOVE TO COMMON AXIS.
DISTANCE C_1 THRU C_4
UNCHANGED.

FIG. VI-2

B. A second possibility giving similar results is keeping the same radius as the ellipse and same slope at the intersection of the horizontal ray while moving the center of the radii to the vertical axis. This increases the eye to surface distance and also the distance between foci (assumed to be where the horizontal ray from the eye reflected from the surface crosses the vertical axis), as shown in Figure VI-1, Curve 3. Again the system is formed by rotating the resulting curve about the system axis. A 15° up ray from the eye when using this approximation on system 3 misses the second surface entirely (Figure VI-3).

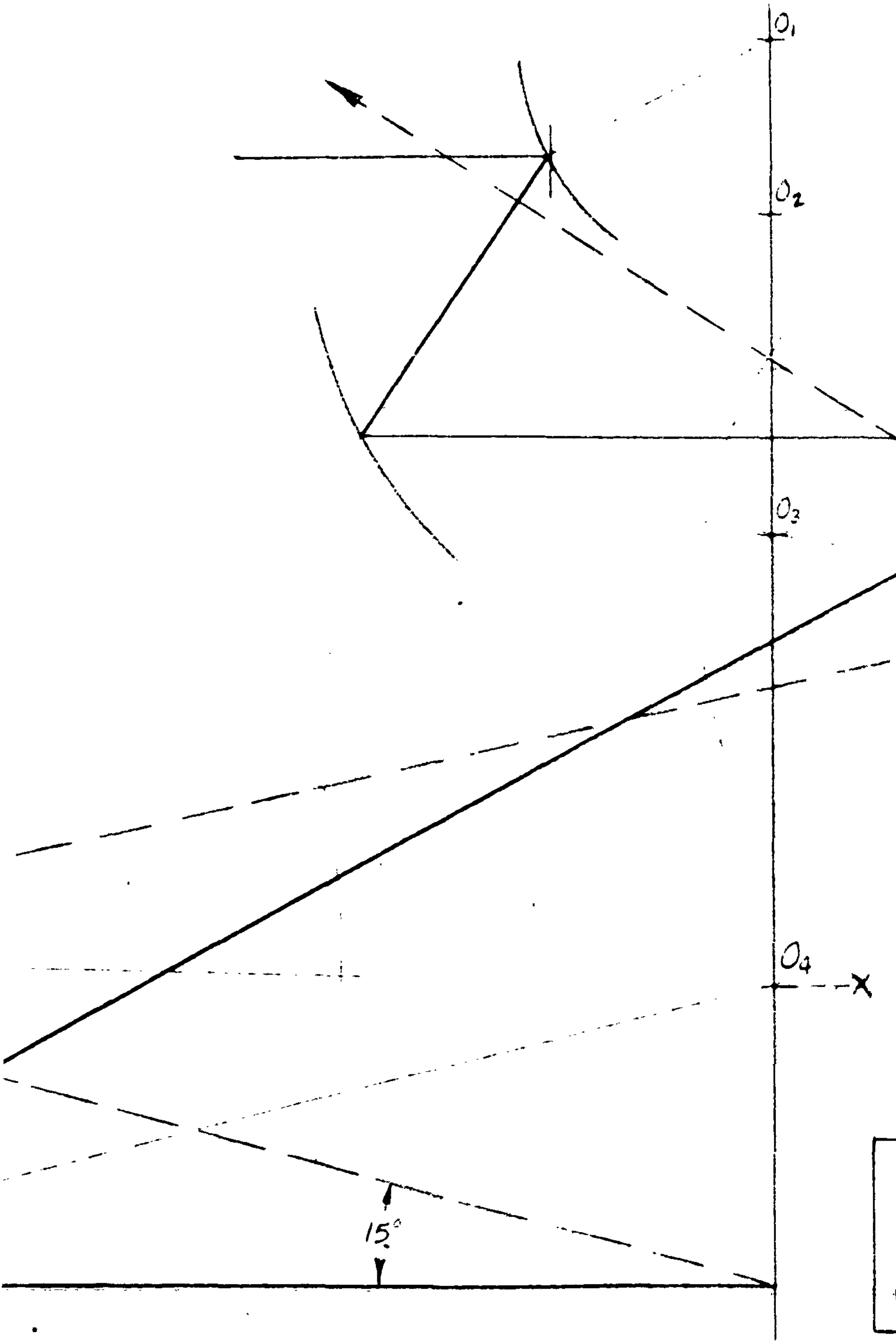
C. The third possibility is to form the surfaces by rotating the desired ellipse about a vertical axis through its center of curvature instead of the vertical axis of the foci. This gives a circle in a horizontal section that is not centered over the eye. The system profile formed by passing vertical planes through the vertical axis would be different at every azimuth. (Figure VI-4.) Unlike the two previously considered cases, the profile for the view ahead would be the desired elliptical curves and no distortion would be present. As the view moved to either side, distortion would be introduced.

The procedure for tracing a ray through the system, other than directly ahead, becomes much more complicated as the rays no longer remain in the vertical plane in which they start. Examining the reflection of a horizontal ray in a plane through point P and P' shows only the ahead ray to be reflected back in the same vertical plane. For other rays the eye, center of curvature and surface intersection are not in a straight line and the ray will be reflected horizontally at an angle to the incoming ray as well as vertically. It becomes



1

FIG. VI-3



SYSTEM #3
CENTERS OF CURVATURE MOVED TO COMMON AXIS.
RADIUS OF CURVATURE UNCHANGED.

2

FIG. VI-3

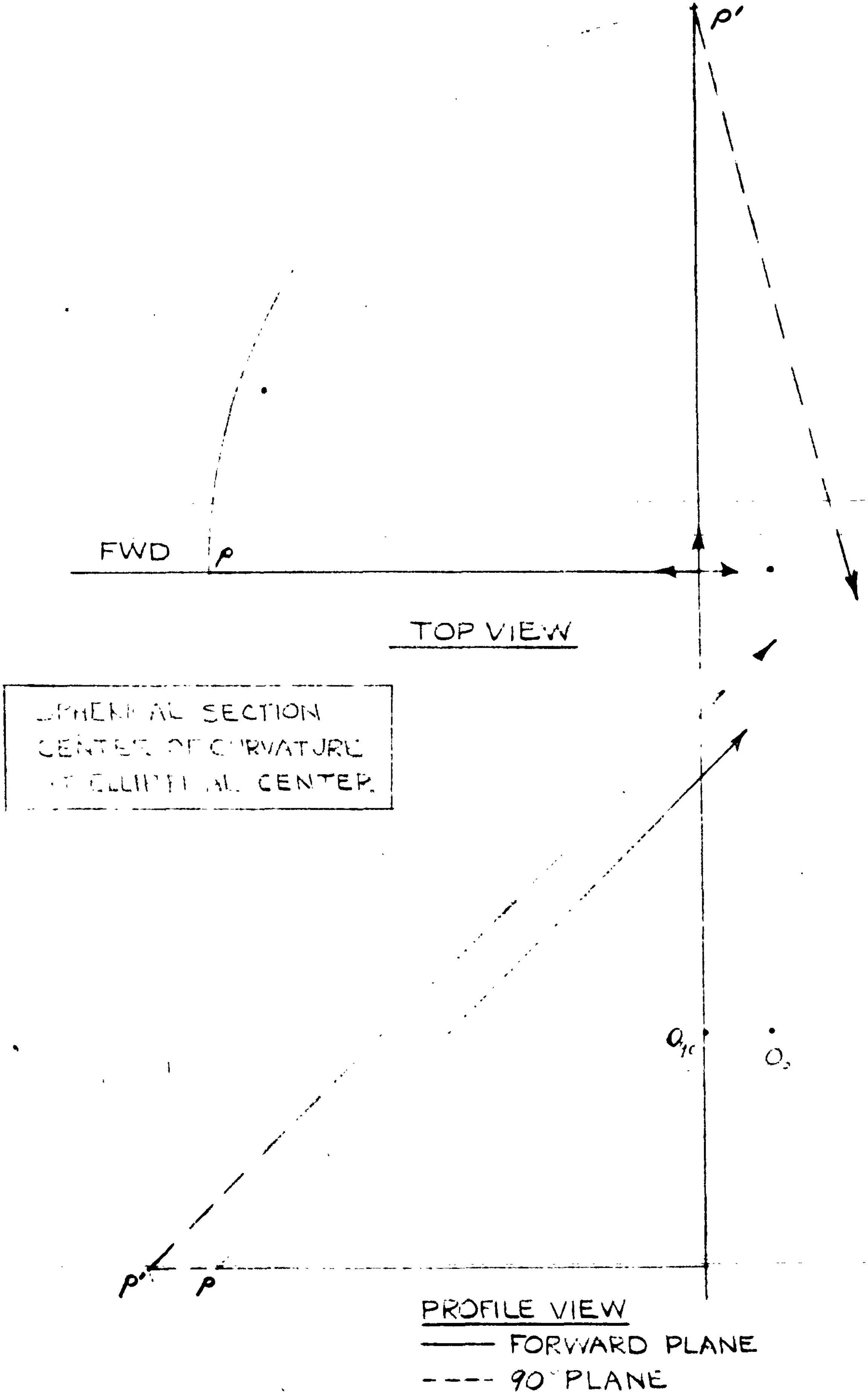


FIG. VI-4

necessary to use a three dimensional ray trace as outlined in Appendix B to determine the path through the system.

A number of these traces were made using several of the systems of section V to determine the amount of distortion present. Figure VI-5 thru VI-9 gives the results of some of the traces which are representative of all the systems. The views shown are the projection of the ray trace on a vertical plane through the ahead or 0° position and the projection on a horizontal plane. The results are tabulated below in Table VI-1.

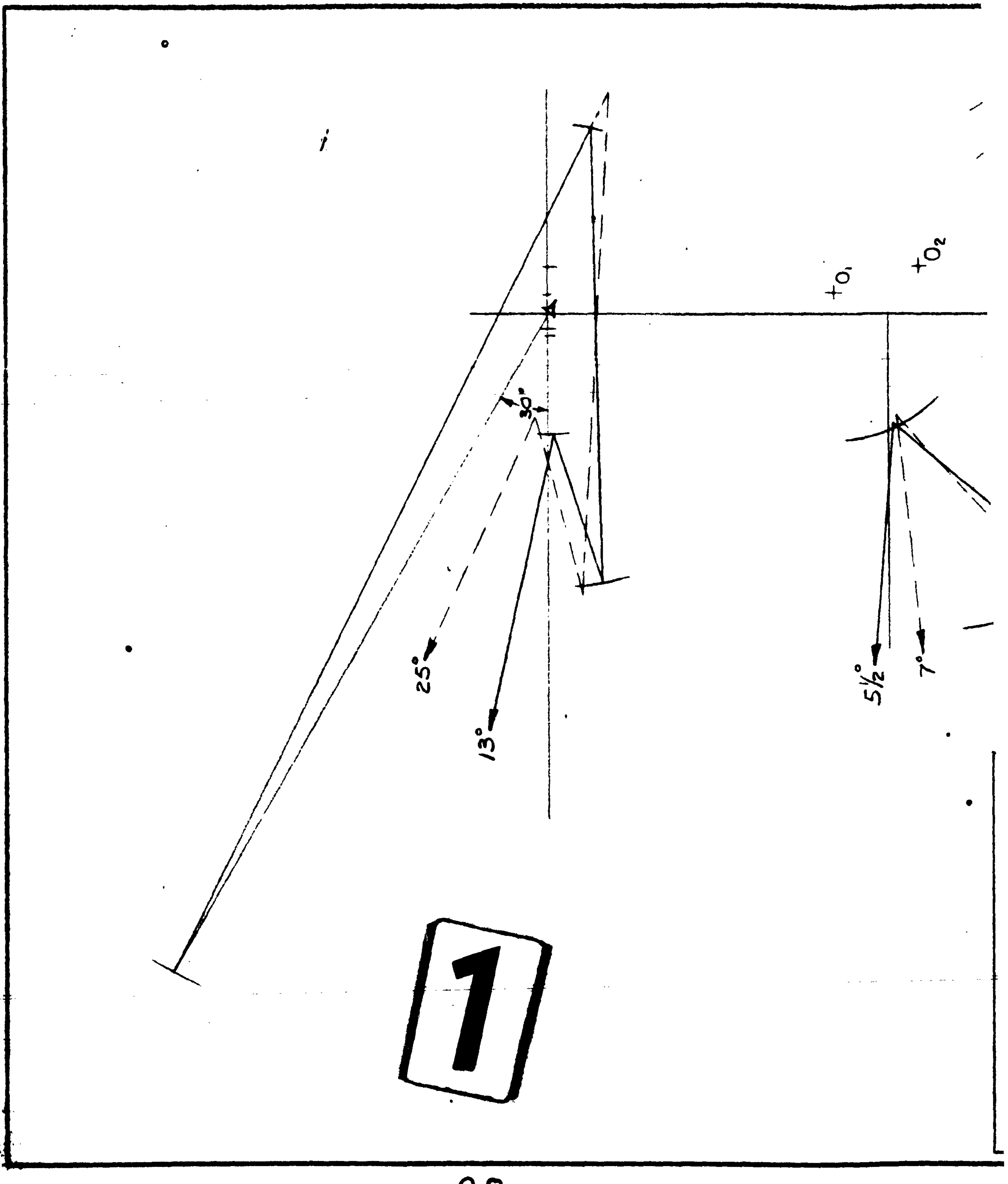
TABLE VI-1

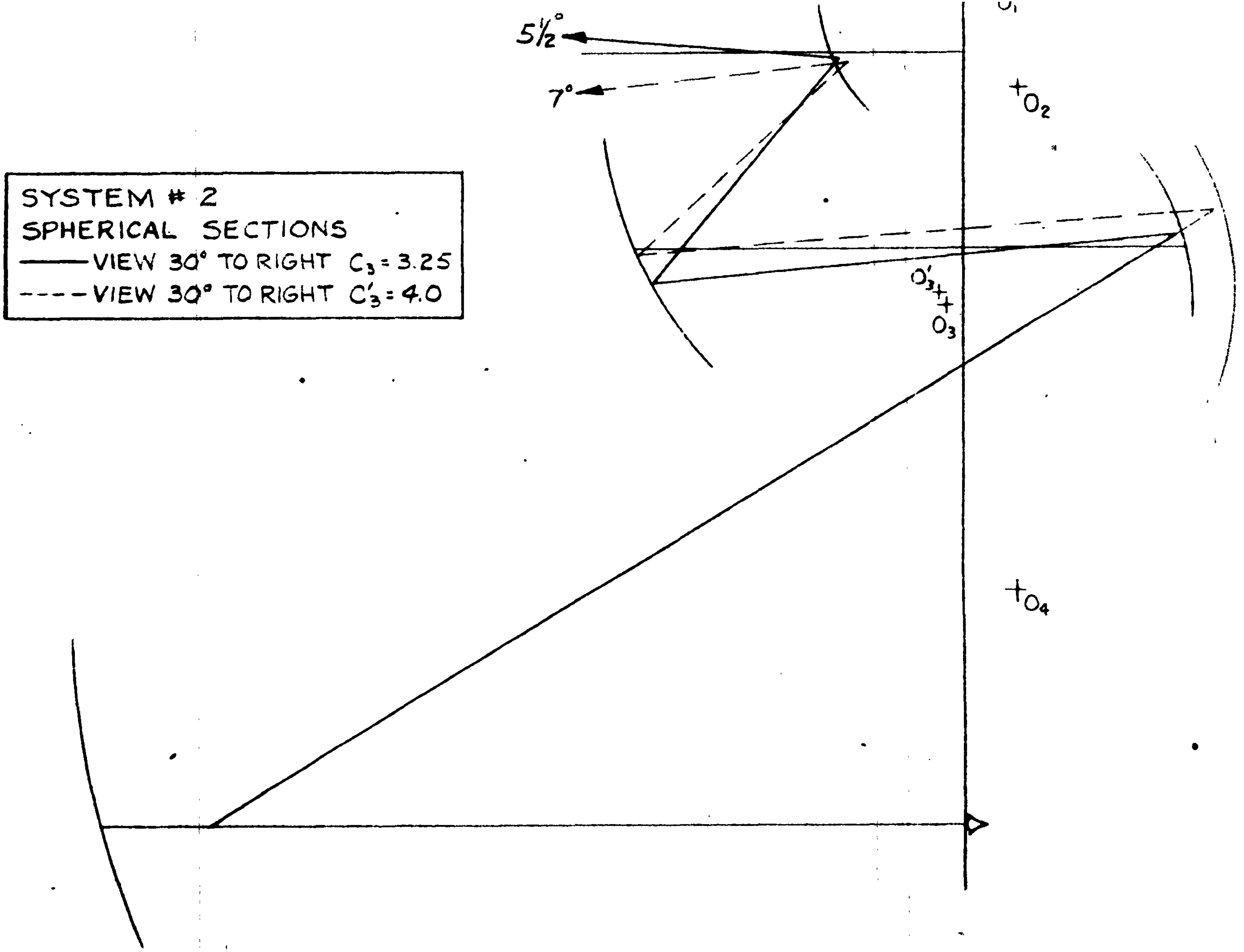
Distortion Due to Spherical Approximation

		Ray from Eye		Ray from First Surface	
Figure	System	Horiz	Vert	Horiz	Vert
VI-5	2	30° R	0°	13° R	5.5° up
VI-5	2	30° R	0°	25° R	7.0° down
VI-6	3	30° R	0°	13° R	2.0° up
VI-6	3	30° R	15° up	19° R	19.5° up
VI-7	3	90° R	0°	80° R	20.0° up
VI-7	2	90° R	15° up	82° R	65.0° up
VI-8	4	30° R	0°	12° R	2.0° up
VI-9	6	30° R	0° up	21° R	2.5° up

As can be seen from the table, distortion is present in both the horizontal and vertical direction. For instance, if the pilot were looking into system 2 at 30° to the right and horizontal (Figure VI-5), he would see an object located at 13° to his right and 5.5 degrees above the horizon. Little difference is seen for the systems considered.

The results of the previous investigations fairly clearly show spherical approximations to the ellipsoids of revolution are not acceptable if any amount of undistorted view is desired. This approach was therefore dropped and further system analysis was confined to the elliptical system.

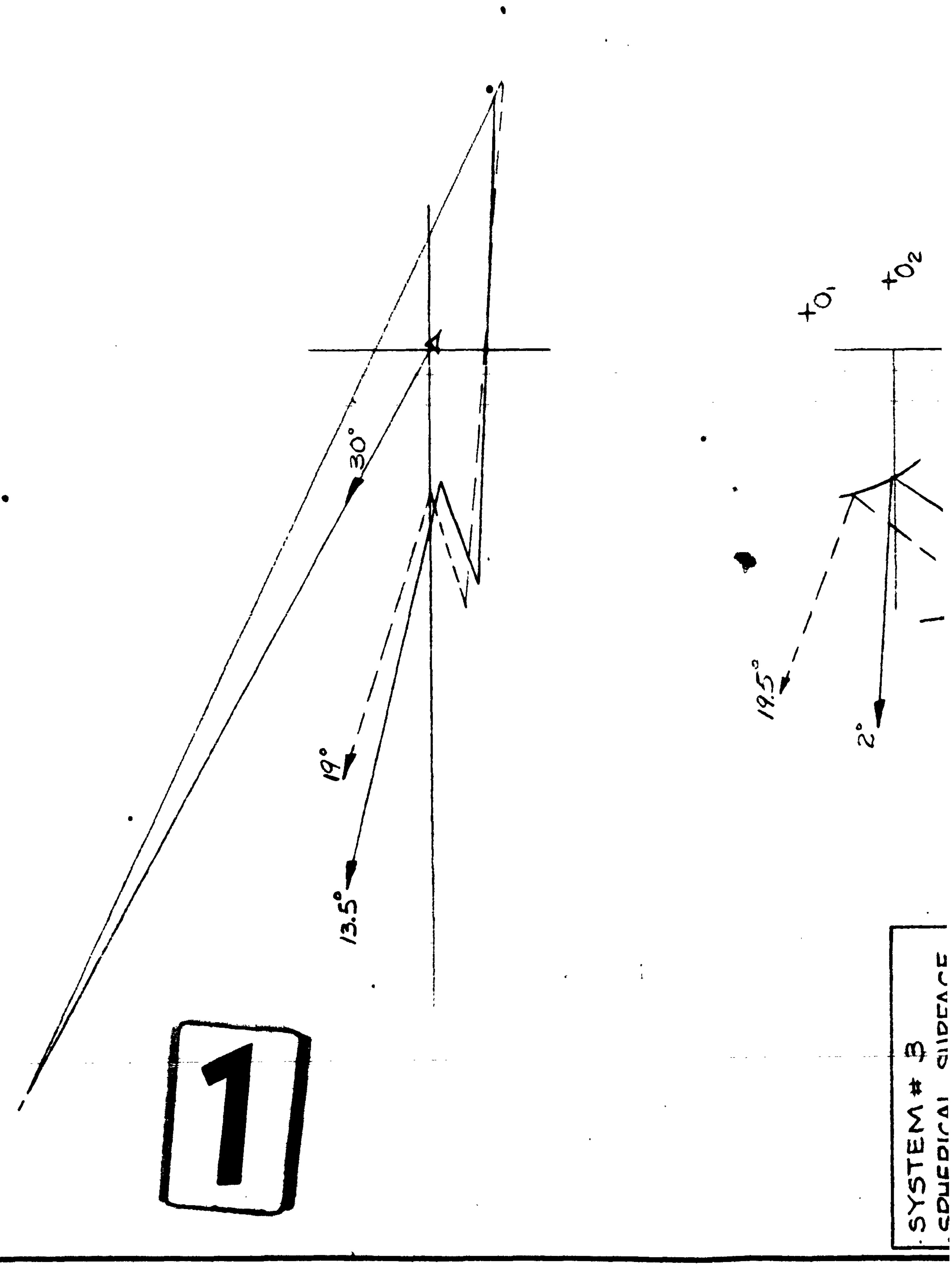

30°
25°
13°
O_1
O_2
5½°
7°
1



SYSTEM # 2
SPHERICAL SECTIONS
—— VIEW 30° TO RIGHT $C_3 = 3.25$
- - - - VIEW 30° TO RIGHT $C_3' = 4.0$
$5\frac{1}{2}°$
7°
O_2
O_3'
O_3
O_4

2

FIG. VI-5


30°
19°
13.5°
19.5°
2°
O_1
O_2
1
SYSTEM # 3
SPHERICAL SURFACE

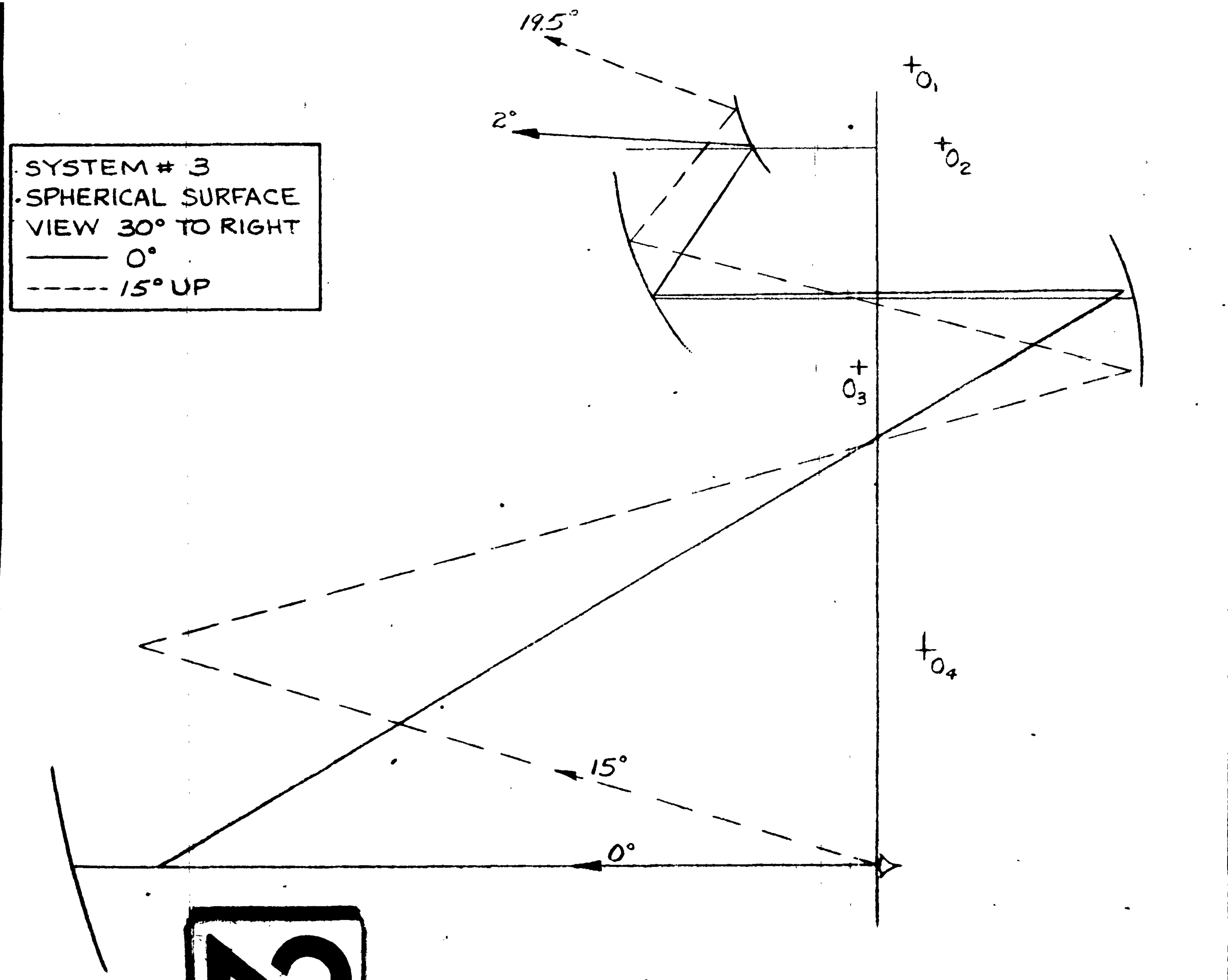
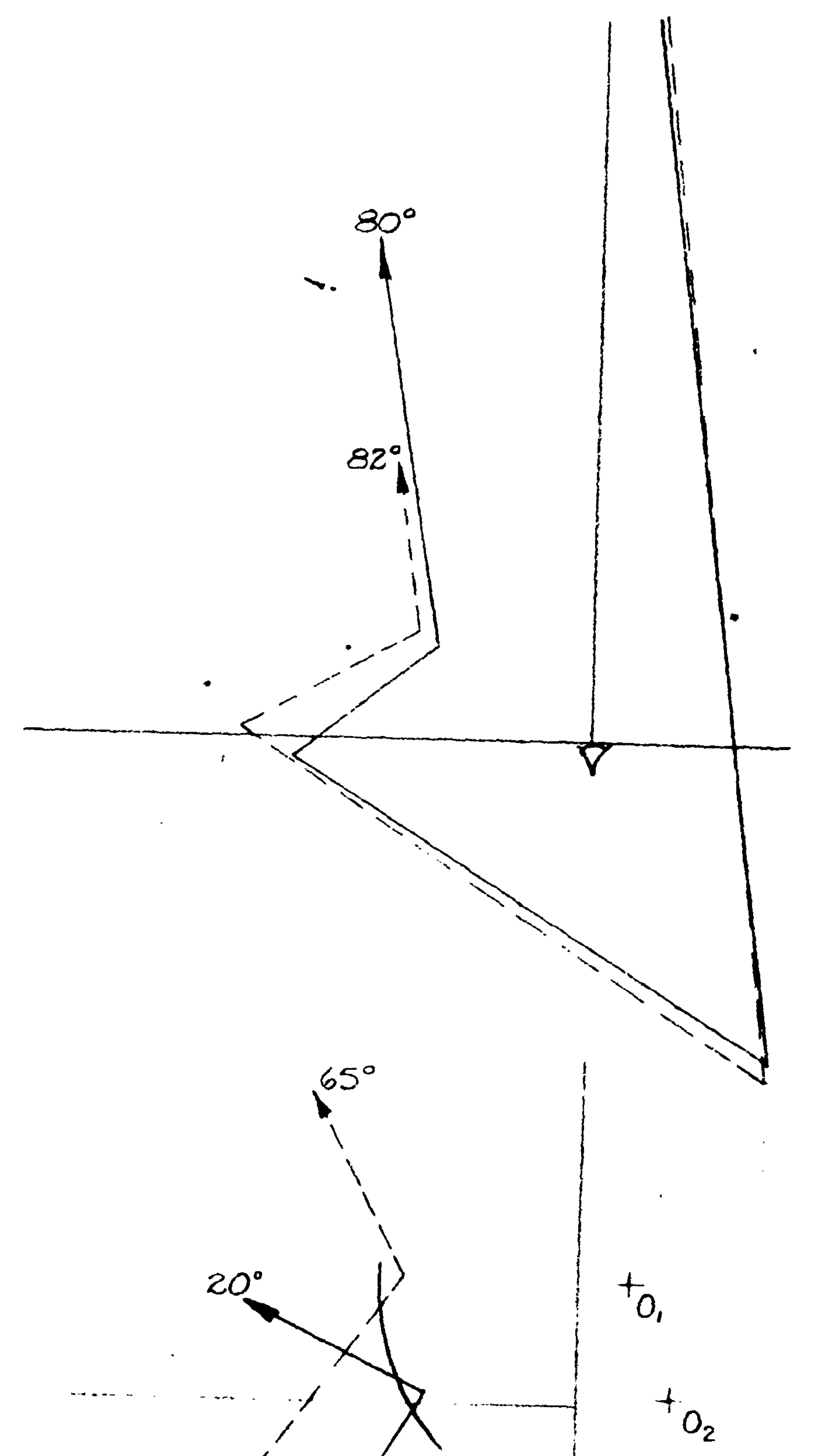

SYSTEM # 3
SPHERICAL SURFACE
VIEW 30° TO RIGHT
0°
15° UP
19.5°
2°
O1
O2
O3
O4
15°
0°
2

FIG. VI-6



SYSTEM # 3
SPHERICAL SURFACE
VIEW 90° TO RIGHT
——— HORIZONTAL

1

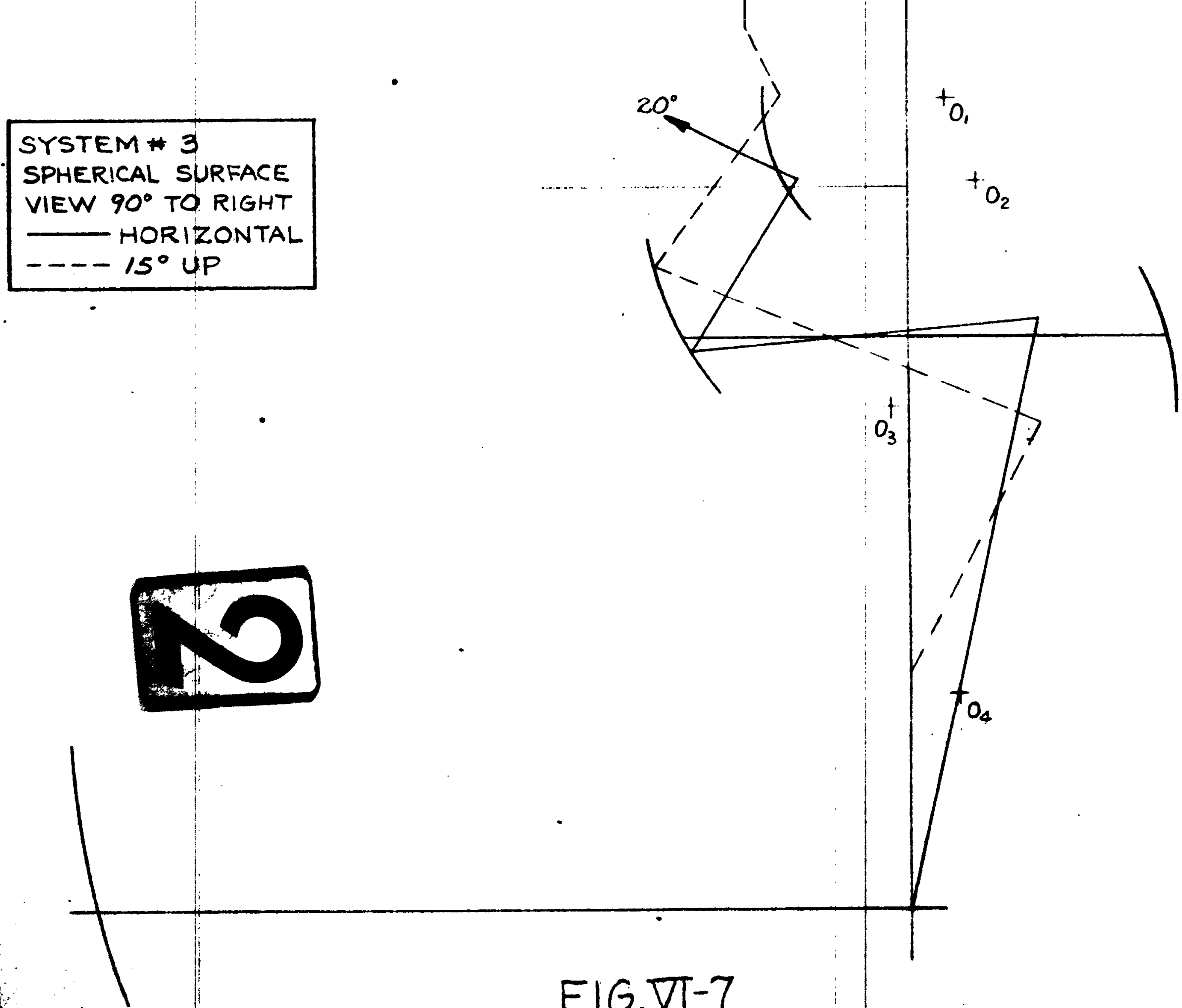
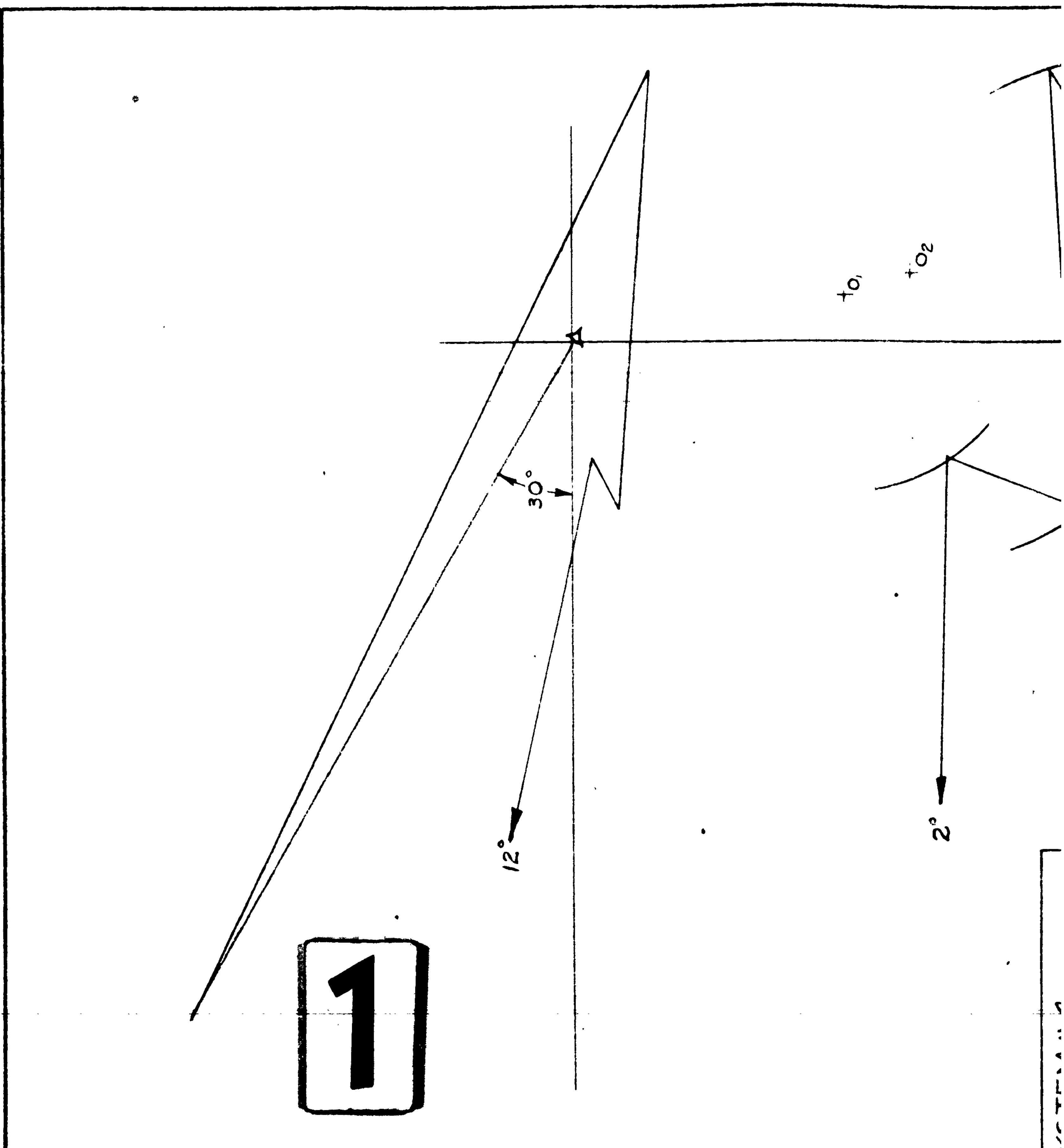

SYSTEM # 3
SPHERICAL SURFACE
VIEW 90° TO RIGHT
——— HORIZONTAL
- - - - 15° UP
20°
O_1
O_2
O_3
O_4
2

FIG.VI-7


30°
12°
2°
O1
O2
1

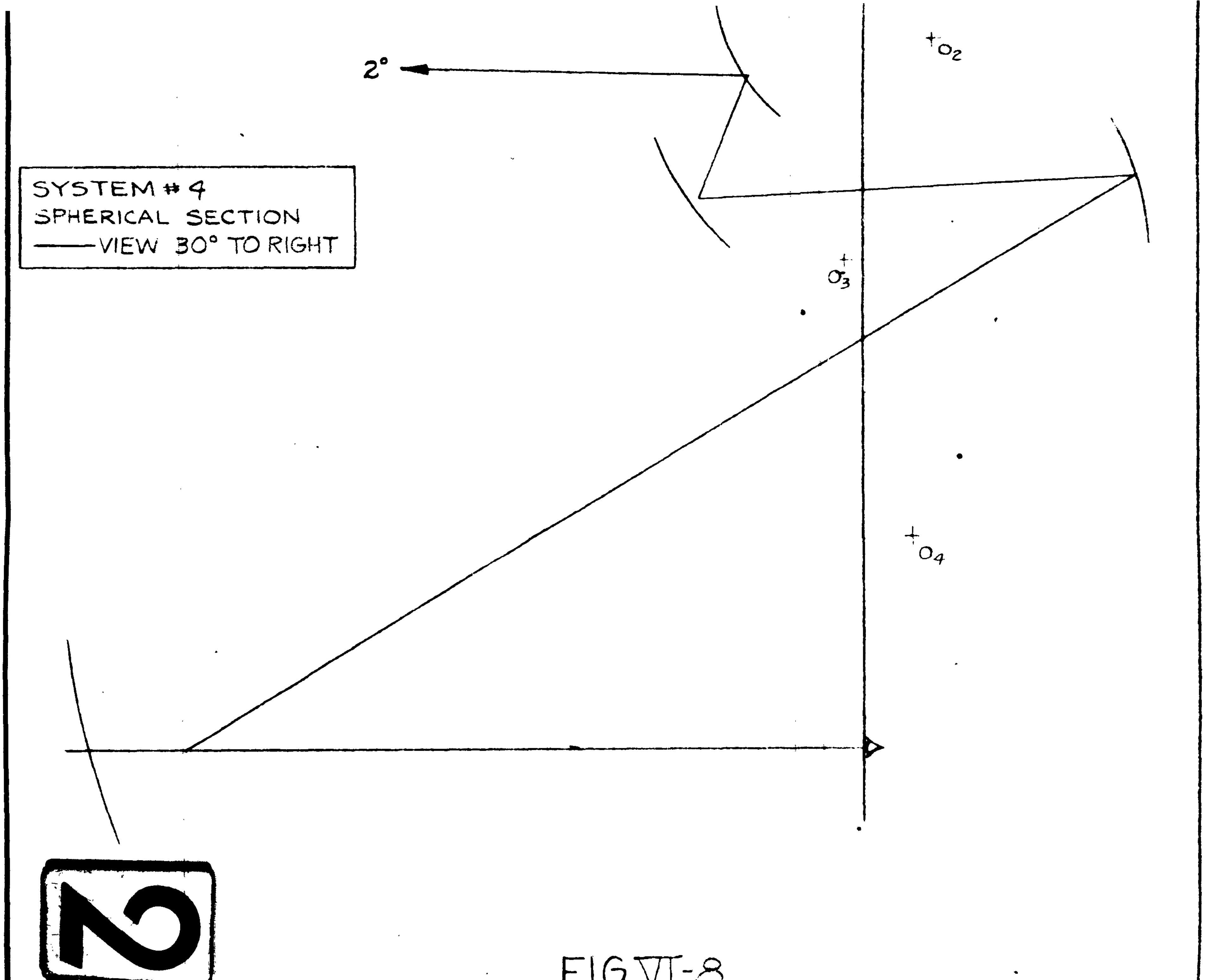
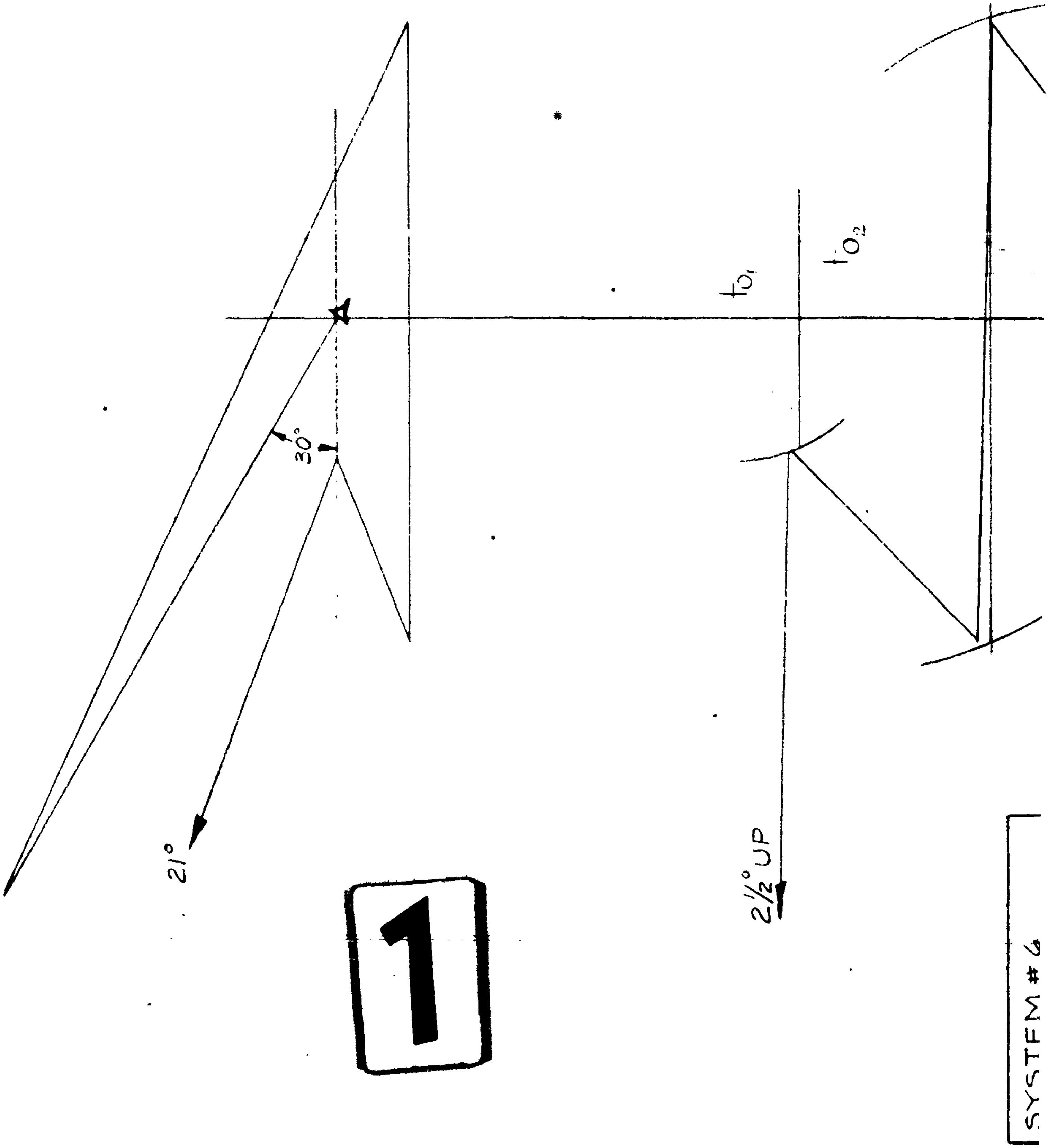


FIG. VI-8



30°
21°
O_1
O_2
2½° UP
1
SYSTEM #6

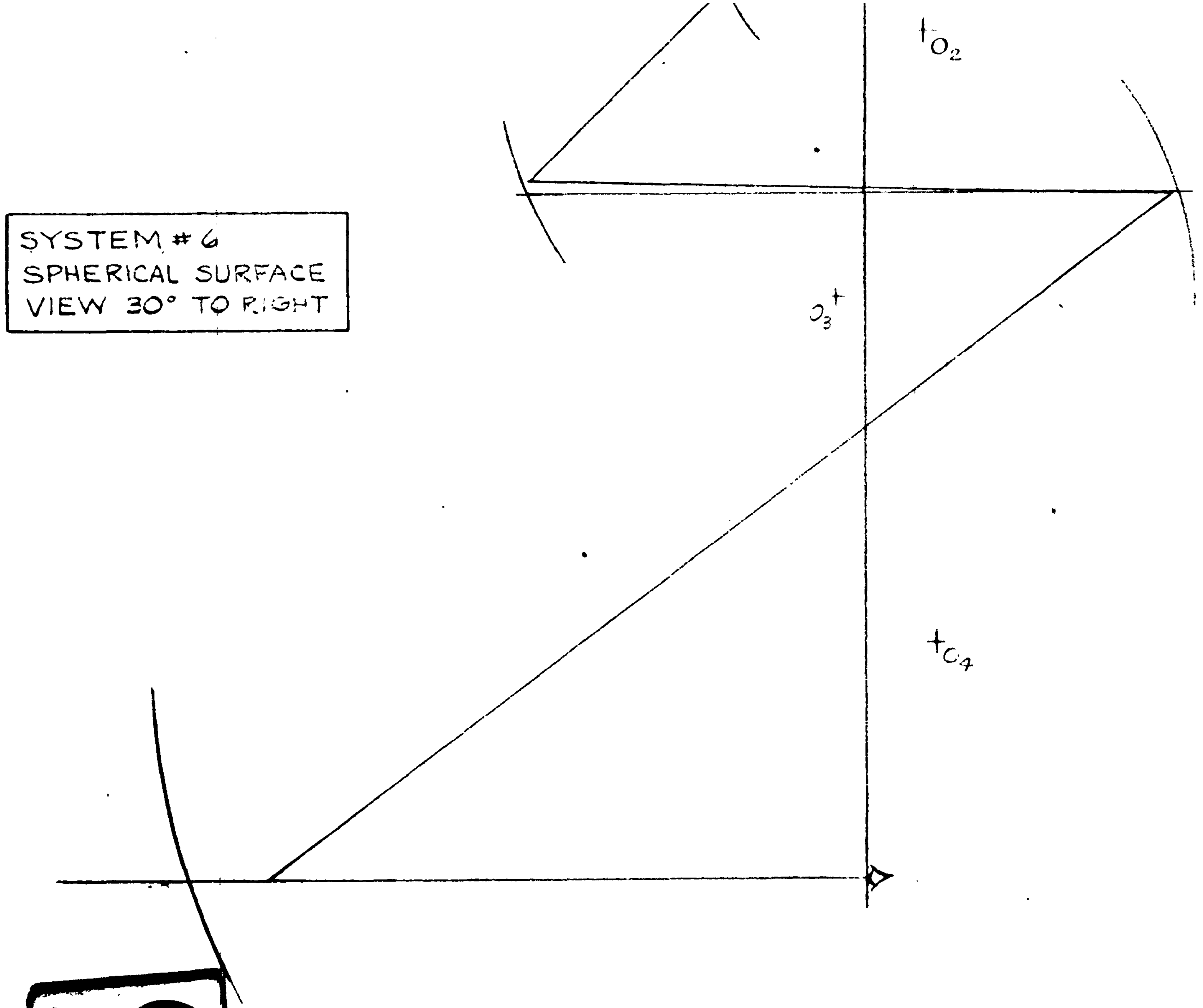


FIG. VI-7

VII. EFFECT OF EYE MOTION

Having established the necessity for elliptical surfaces, several aspects of the system require further investigation. Up to now, the system has had only one eye located on the vertical axis, and is symmetrical about that eye position. With the eye moved off center, such as would be the case with the head centered, this symmetry would be lost and some distortion could be expected. Ray traces were made with the eye in various positions other than at the focus to determine the amount of error introduced.

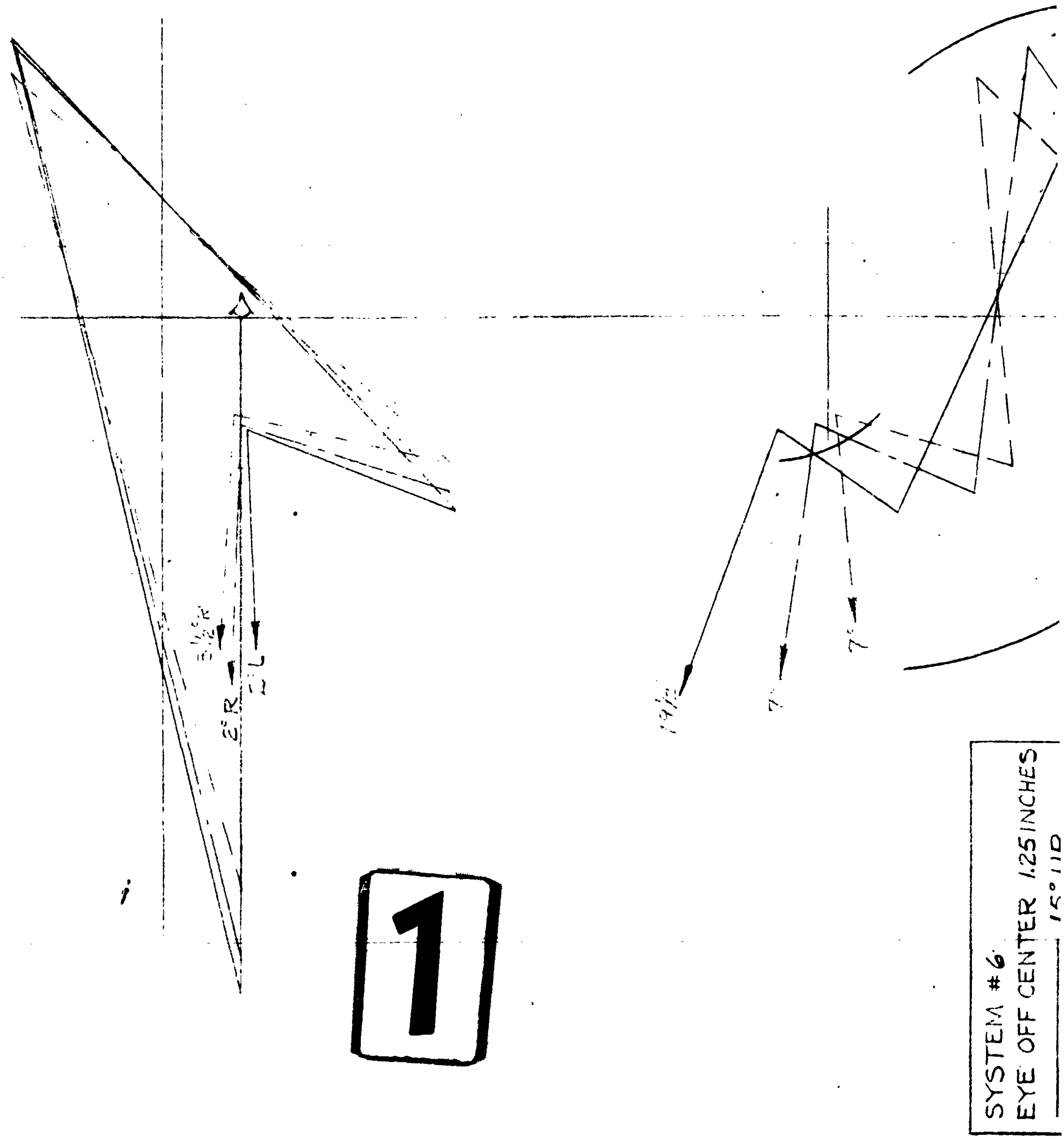
The first case considered was that of moving the head to one side. System 6 was checked with the head centered and the eye 1-1/4 inch off center. Again it was necessary to use a three dimension ray trace. The results are shown in Figure VII-1 and Figure VII-2 and tabulated in Table VII-1.

TABLE VII-1

Effect of Eye Position

Ray from Eye		Ray from First Surface	
Horiz	Vert	Horiz	Vert
0°	15° up	2° L	19-1/2 up
0°	0°	2° R	7 up
0°	15° down	$3\text{-}1/2^\circ$ R	7 down
50° R	0°	51° R	0°

As the head is moved to one side from the foci, the picture seen will appear to move down and rotate to the side opposite the eye motion. (See Figure VII-3.)


2°R
2°L
7°
7°
SYSTEM #6
EYE OFF CENTER 1.25 INCHES

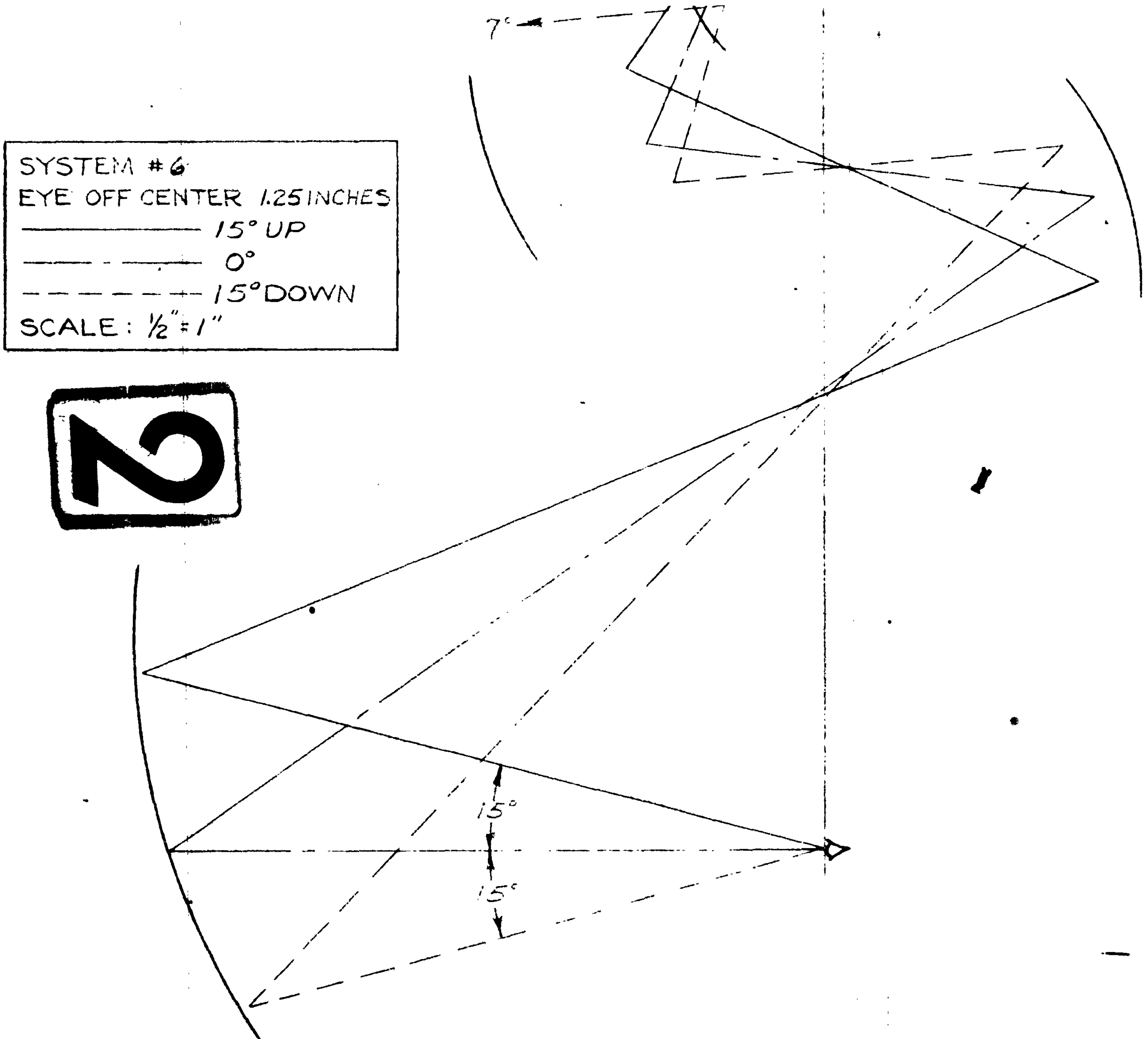
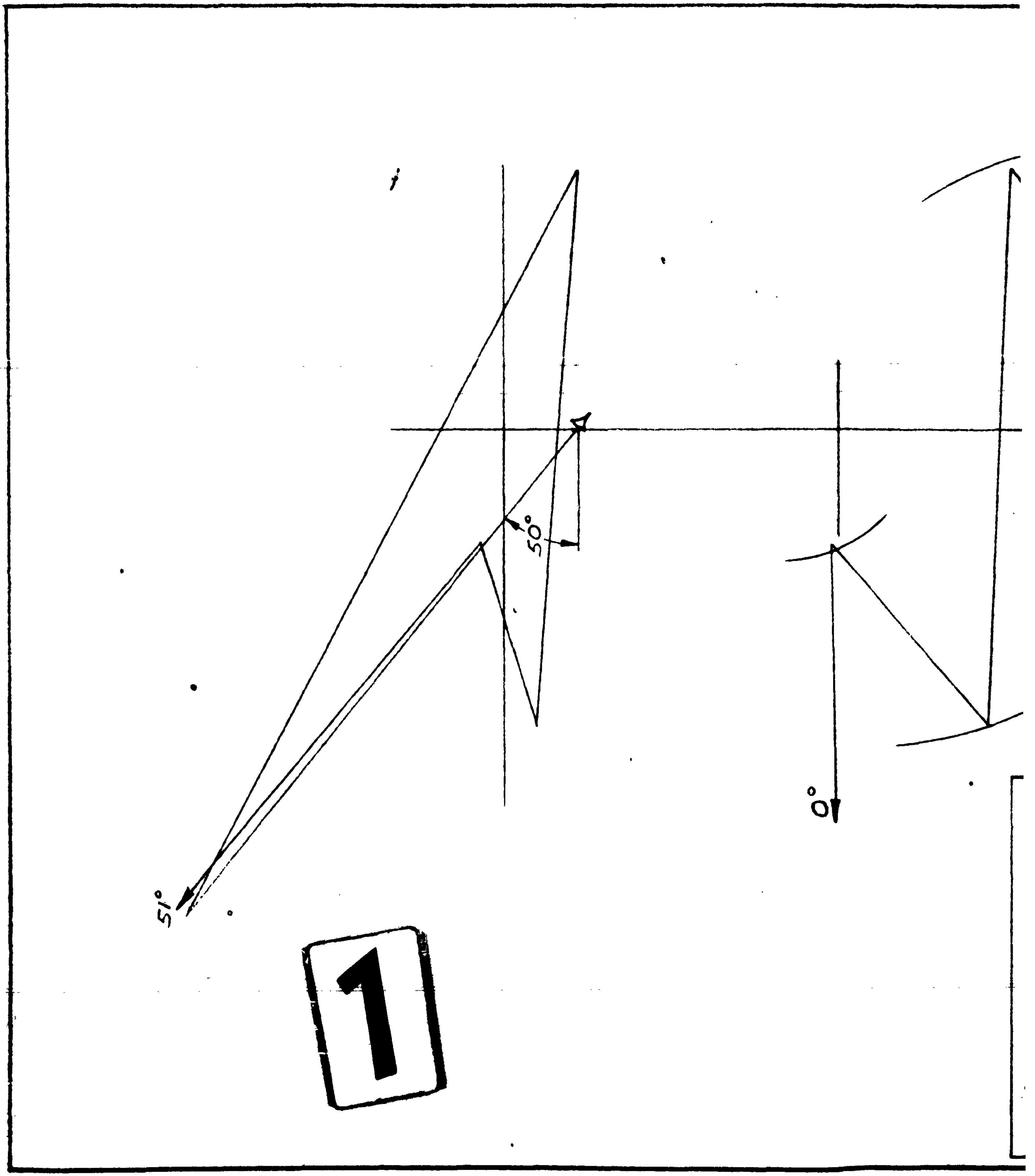

SYSTEM #6
EYE OFF CENTER 1.25 INCHES
15° UP
0°
15° DOWN
SCALE: ½" = 1"
7°
15°
15°
2

FIG. VII-1


50°
51°
0°
1

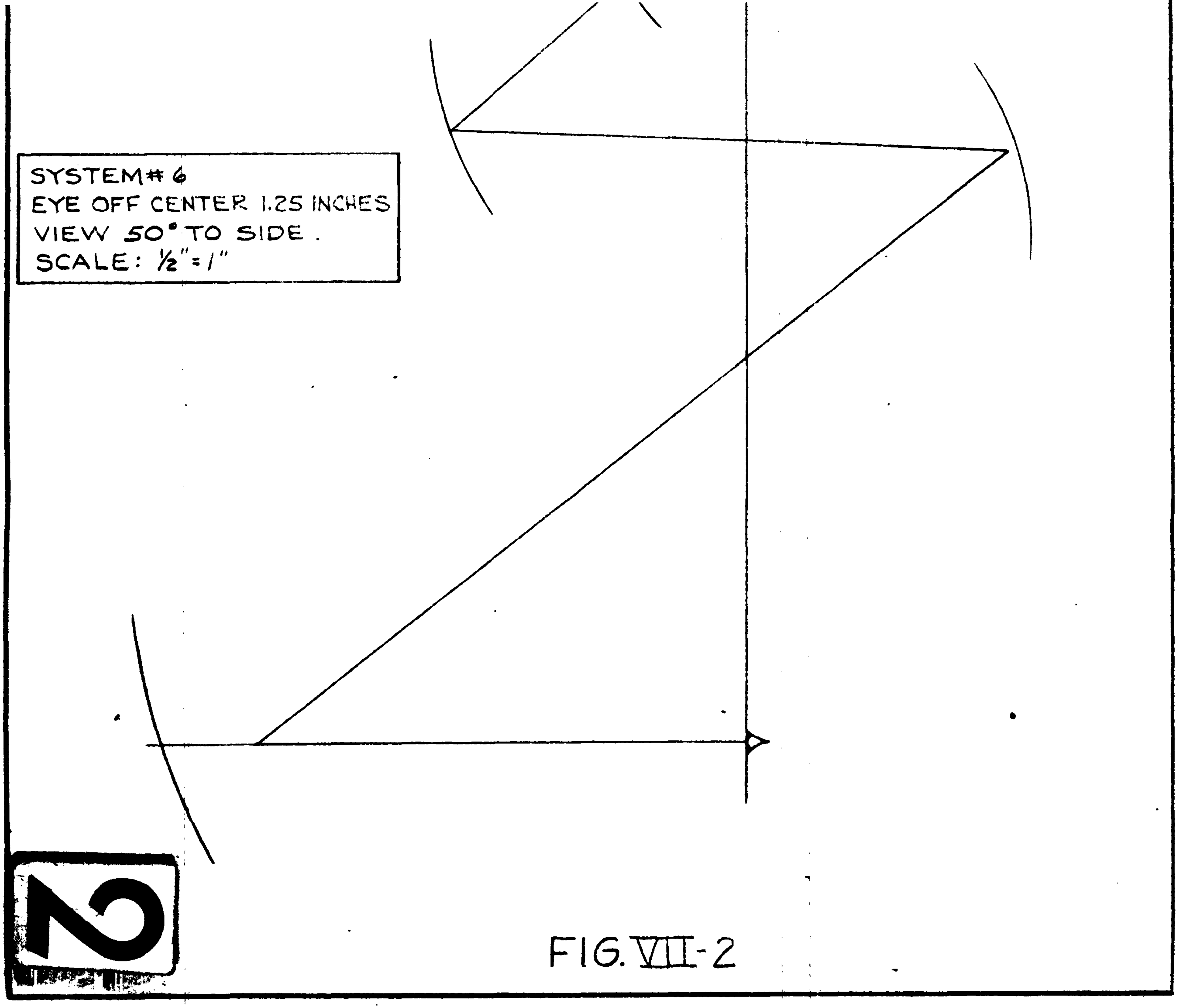
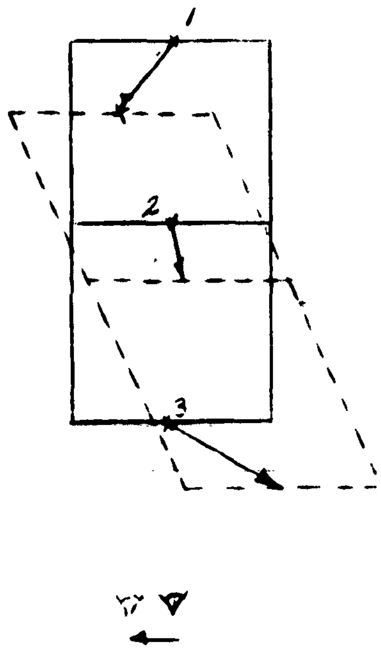


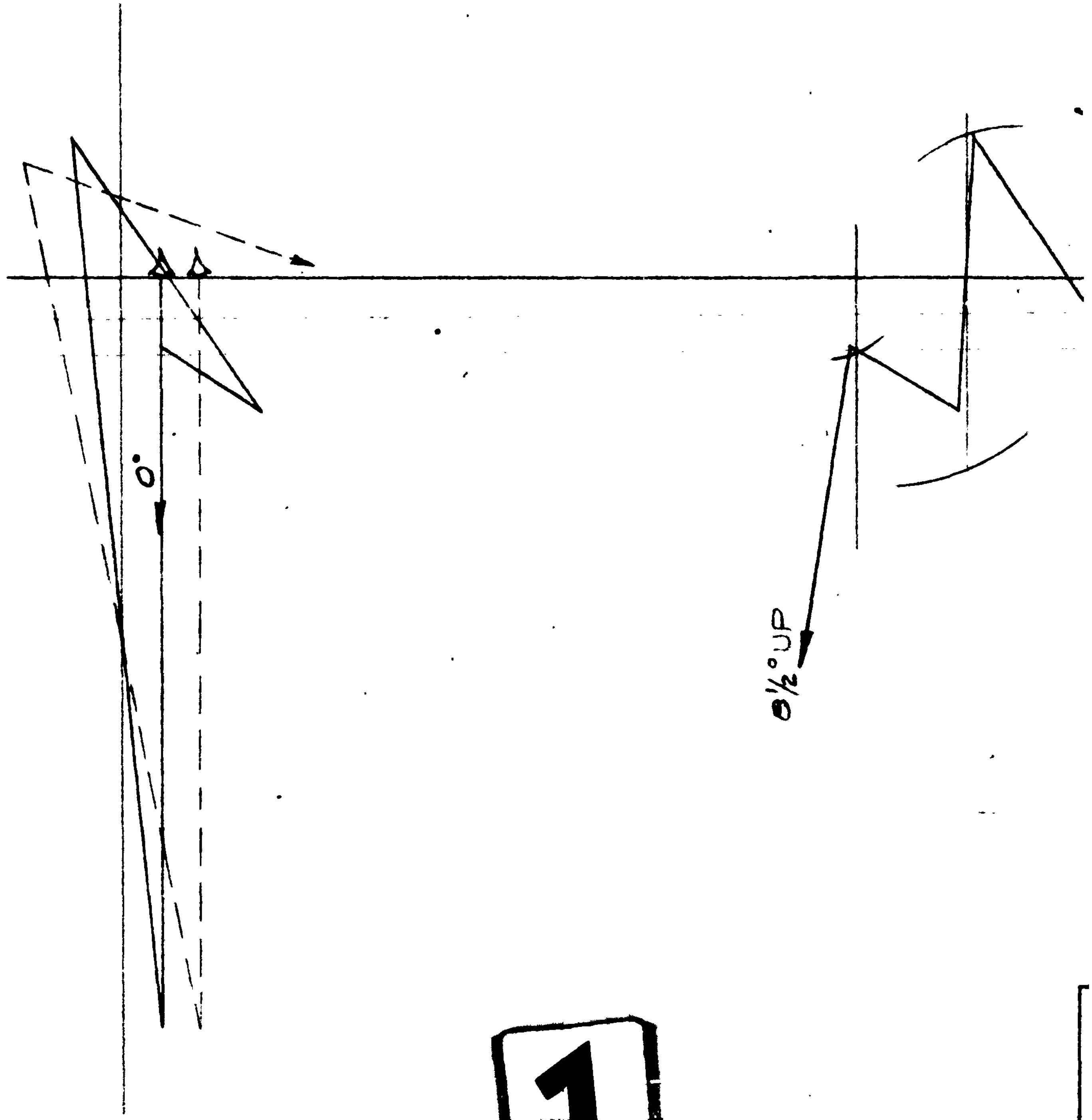
FIG. VII-2

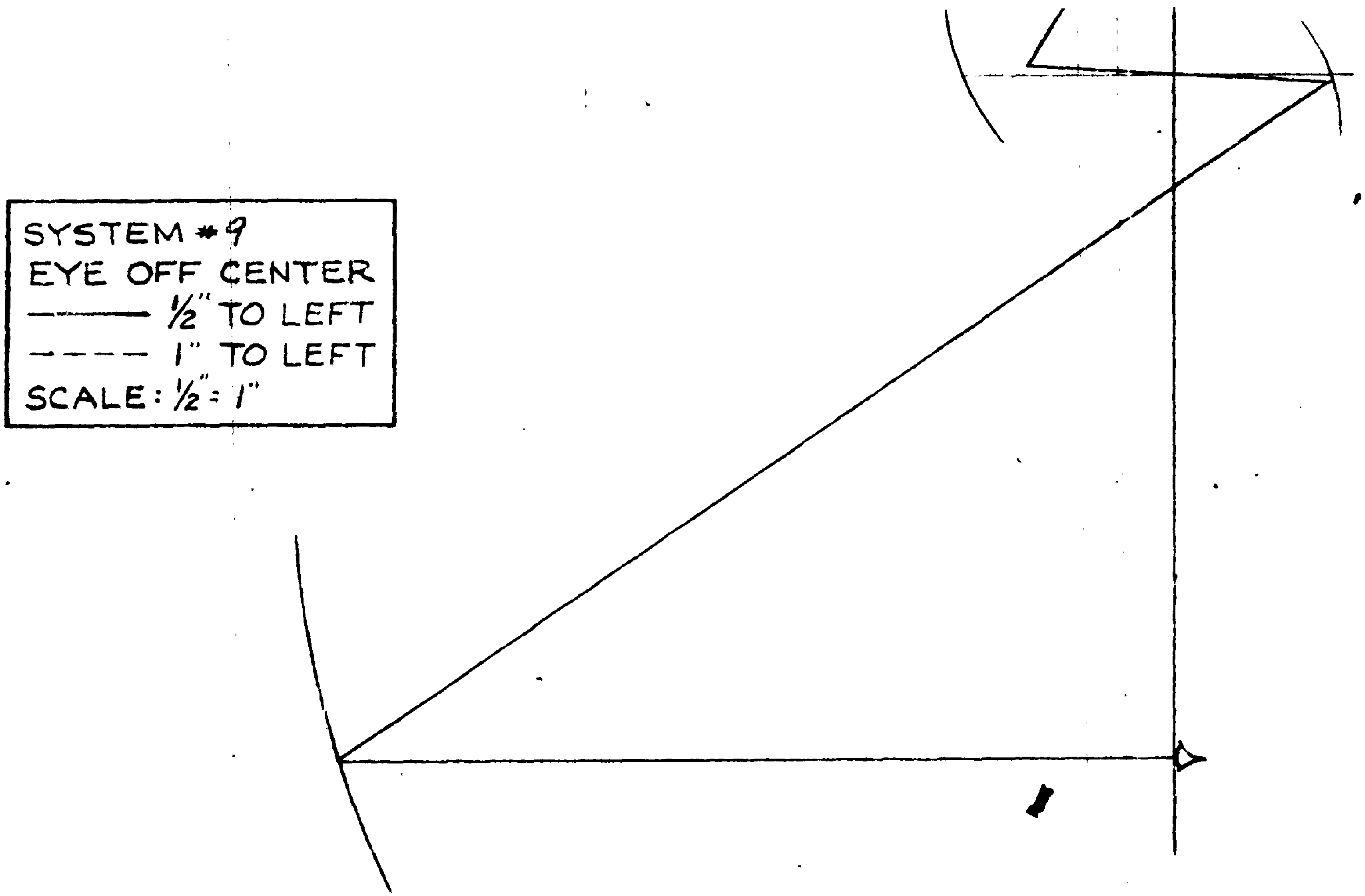


Effect of Lateral Eye Motion
Figure VII-3

Maximum error was found in the ahead position. The size of the system greatly affects the results. With system 2 where the fourth surface was 13 inches instead of 10 inches, the results were similar. Reducing the scale of the upper surfaces, however, to half size (as in system 9), increased considerably the magnitude of the effect. An 8° vertical error when looking ahead was present with only a half inch eye motion, while for an inch motion the ray from the eye would entirely miss the second surface. (See Figure VII-4.)

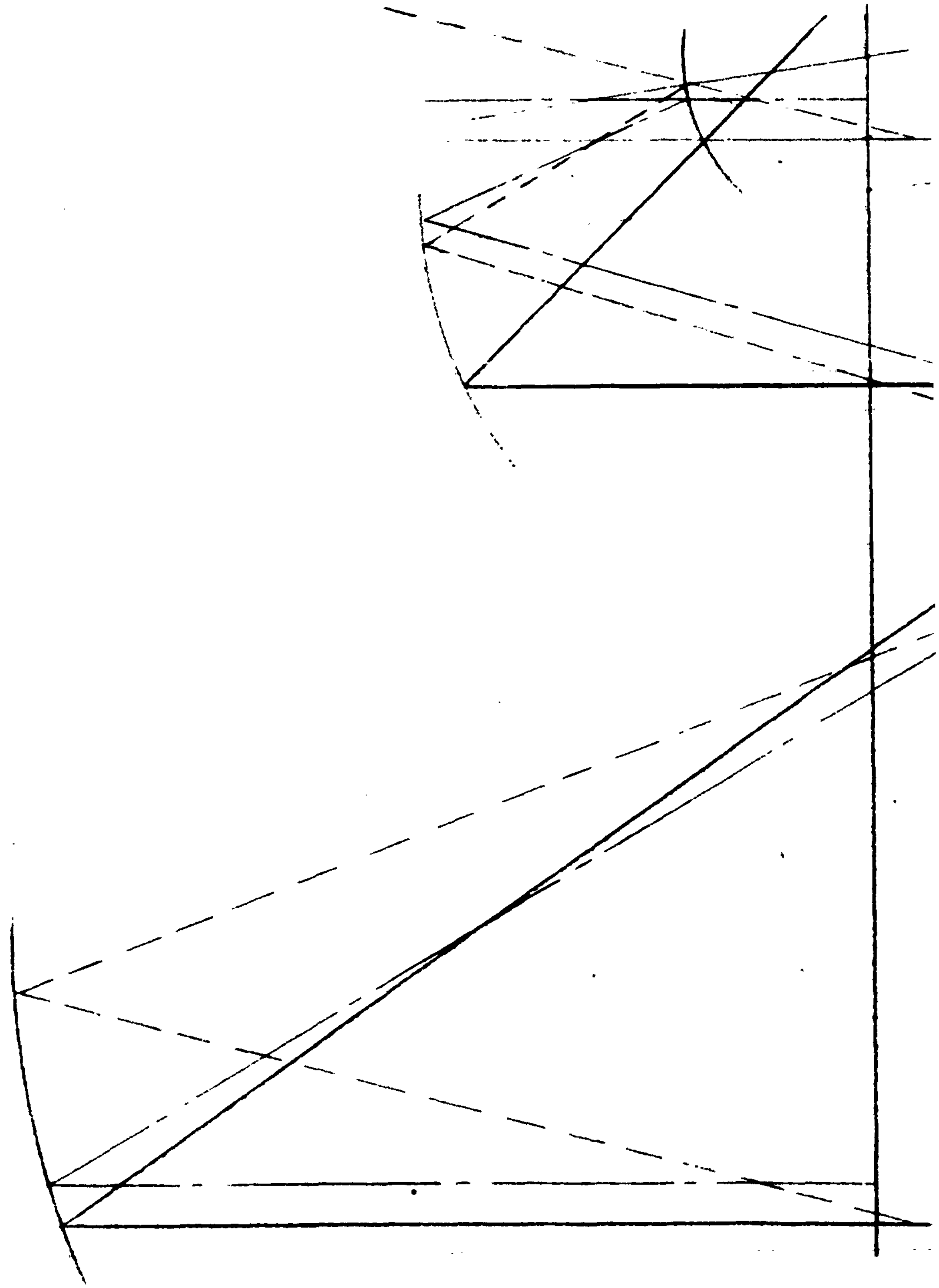
Eye motion, fore and aft or up and down, has the main effect of moving the imaged eye location the same amount. (Figure VII-5.) The view seen would be that of the eye in its new location looking through a window the size of the small mirror. With the eye a half inch above the foci for system 9 for instance, the


0°
8½° UP



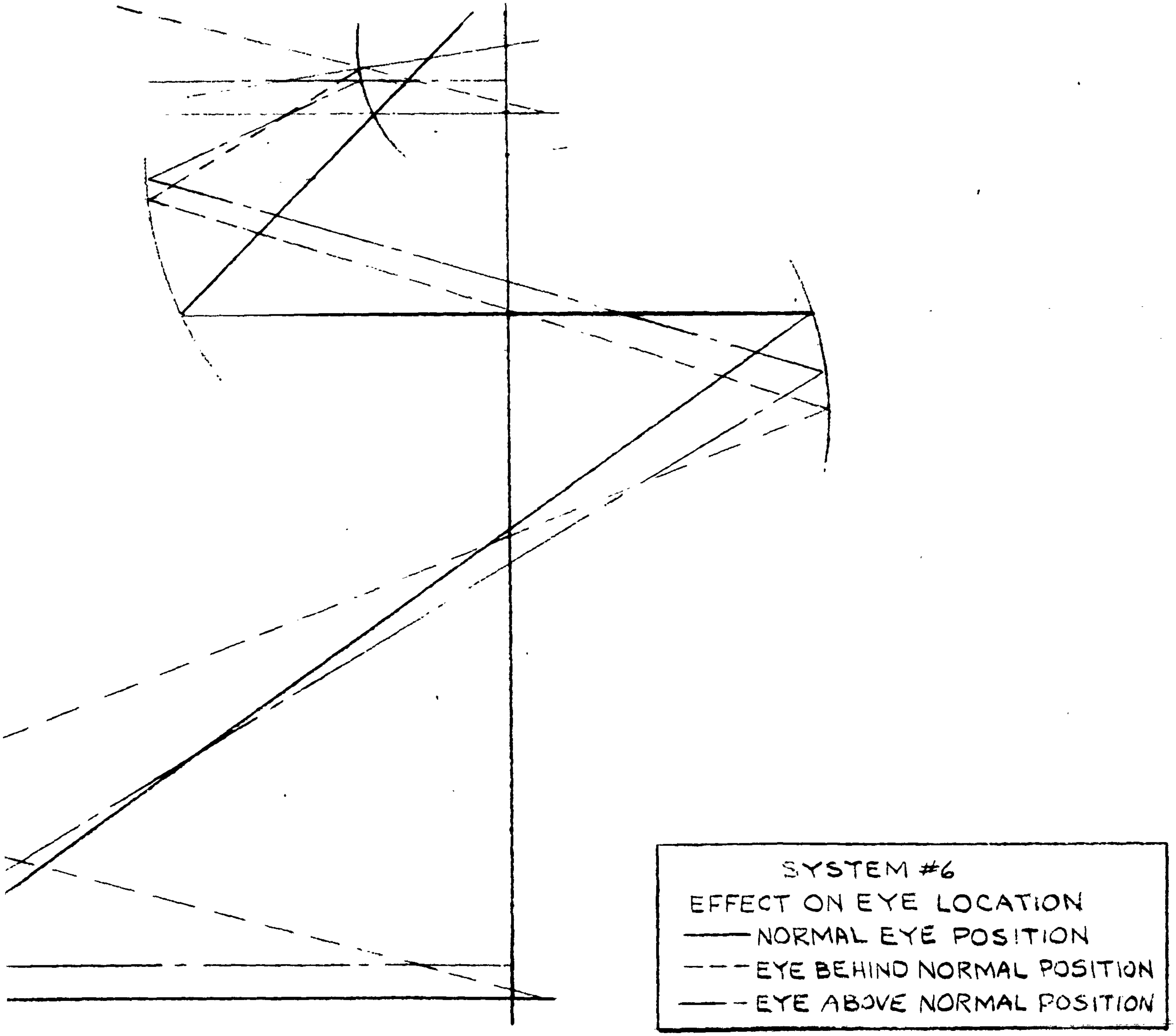
2

FIG. VII-4



1

FIG. VII-5.


SYSTEM #6
EFFECT ON EYE LOCATION
NORMAL EYE POSITION
EYE BEHIND NORMAL POSITION
EYE ABOVE NORMAL POSITION

2

FIG. VII-5.

view seen would be from 1° up to about 29° down. When moving fore and aft in addition to a change in the vertical field of view, distortion would be present at the side due to the eye location being off of the centerline. In both cases, an additional limit on the view seen is imposed by the fact that all of the surfaces do not have the vertical range to accept the accompanying shift in picture location on the surface.

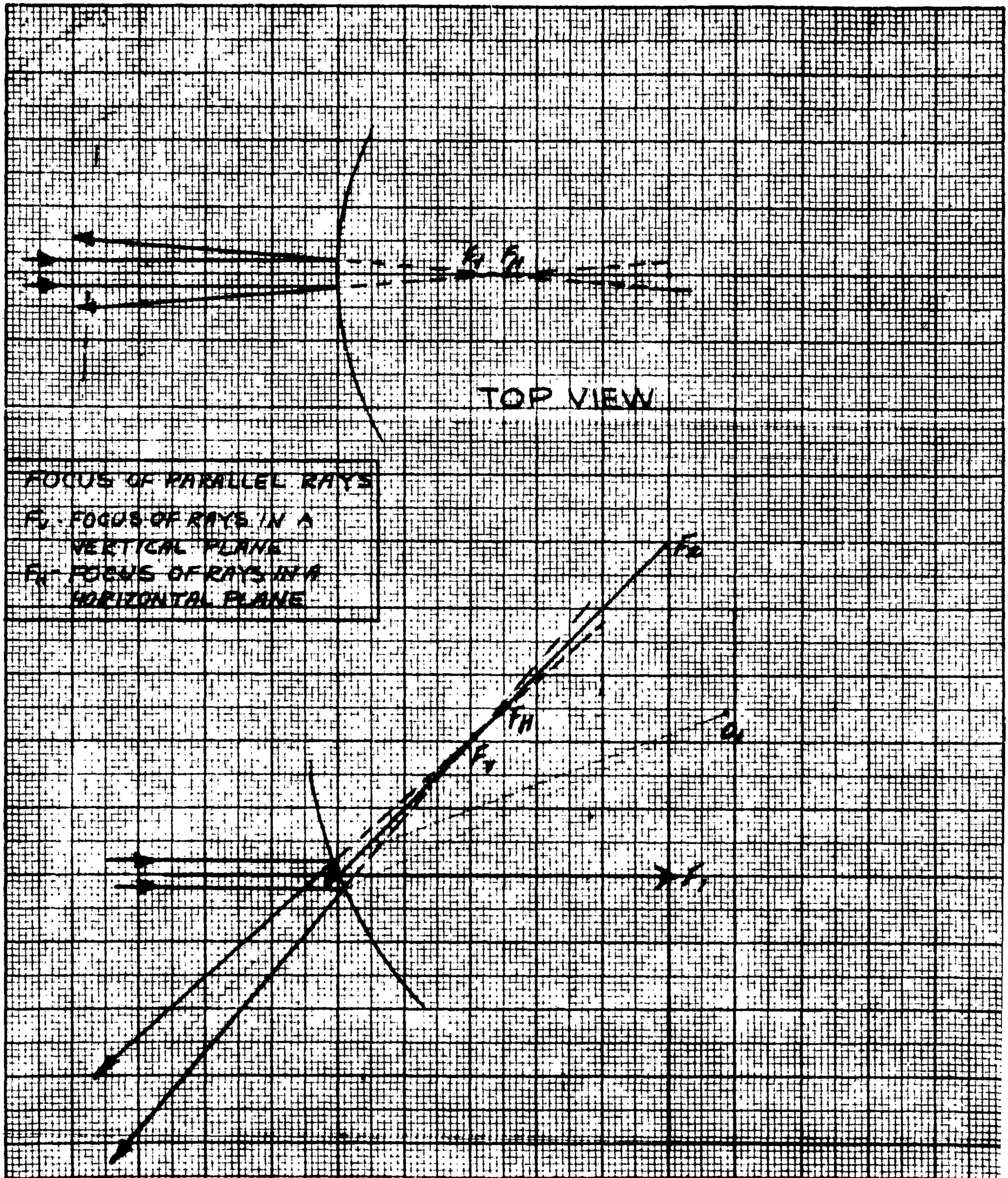
Eye position sensitivity therefore is present in the system and is affected considerably by the scale of the system. For the small scale systems under consideration for the aircraft periscope, the allowable eye motion is very small.

VIII. SYSTEM FOCUS

In section V, the third surface was located graphically so that parallel horizontal rays in a plane through the vertical axis would also enter the eye parallel. The image formed by surface 2 of an object, at infinity in front of surface 1, was imaged by surface 3 at the prime focus of the fourth surface. If this is done perfectly, the third surface would bring the entire picture seen by the eye into focus at infinity.

To improve the accuracy of the results and allow the use of parallel rays which were close together, the ray traces were made mathematically. The equations of the incoming rays and the surfaces are known so that the point of intersection of a ray and surface, and the angle of incidence and reflection can be determined. A ray can be traced to a surface and its reflection determined and traced to the next surface, and through the system. The intersection of the reflection of two incoming rays will be the point at which these rays focus.

A further look at the focusing aspects of the periscope was taken using the upper surfaces of system 9. The location of the images, formed by these surfaces, of three points located at infinity, and at vertical angles of 15° up, 0° and 15° down was determined. This was done by tracing two rays from each point and finding the points of intersection of the reflected rays. The first set of rays was located in a vertical plane containing the point and the vertical axis of the system with the second set of rays in plane perpendicular to the first and containing the point and the eye image or lower foci of the first surface. The profile view of figure VIII-1 shows horizontal incoming rays in a vertical plane focused at F_v on a line from the foci F_2 to point P and .585 inches from the vertical axis.



PROFILE VIEW

FIG. VIII-1

Parallel incoming rays in a horizontal plane through point P are focused at F_h, which is along the same line but .50 inches from the vertical axis. These two sets thus form images that are not located at the same point because of the difference in radius of curvature of the intersection of the surface and the two perpendicular planes. Doing the same for the other two points and continuing through the second surface gives the results shown in Figure VIII-2. F_v is the location of the images formed by the vertical rays and surface 1. Its location is as predicted, but does not coincide with F_h, the focus of the horizontal rays. If the image F_v is used as the object of the second surface and vertical rays used, the resulting image F_v' is obtained. Not only does it not coincide with F_h', but the slope is not parallel to surface 3 as initially expected.

The effect of surface 3 location on the image formed is shown in Figure VIII-3. It is assumed that the first two surfaces image two incoming parallel rays at point O. Where the third and fourth surfaces image, this point is examined as surface 3 is moved from the point, and from the vertical axis, keeping the same eccentricity as surface 4. As surface 3 moves out, the resulting image moves from surface 3 to infinity behind the surface and then from infinity in front of the surface back to the other foci. Surface 4 images the object from foci F_5 through the mirror to infinity and then from infinity in front of the surface back to approximately F_5. For the image seen by the eye to appear to be at infinity, surface 3 should be between position C and D. Forward of this, the image will appear to come from a point closer than infinity, while back from this location, the image will be formed behind the pilot's head.

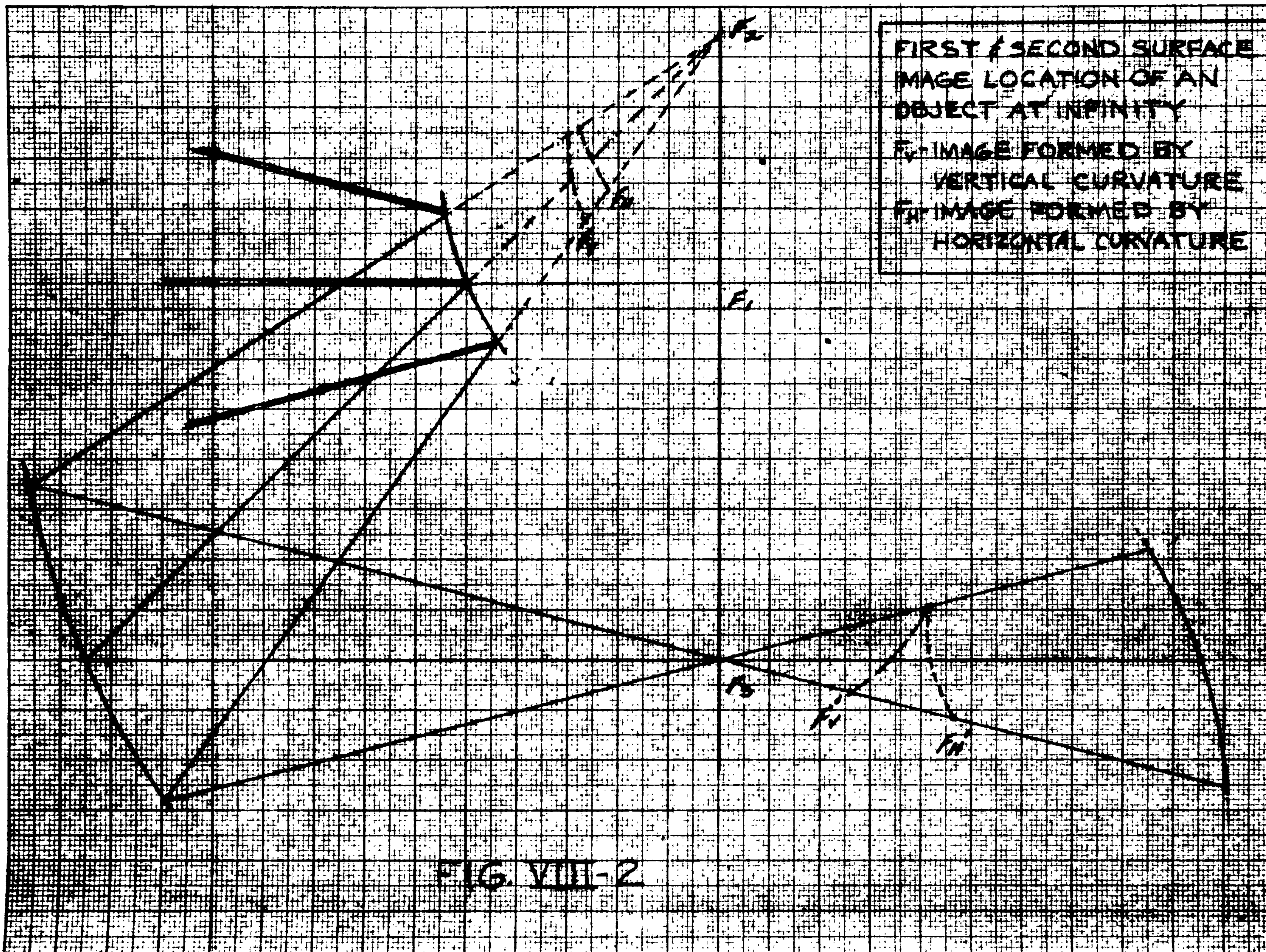

FIRST & SECOND SURFACE
IMAGE LOCATION OF AN
OBJECT AT INFINITY
F_V - IMAGE FORMED BY
VERTICAL CURVATURE
F_H - IMAGE FORMED BY
HORIZONTAL CURVATURE
F_2
F_1
F_3
F_V
F_H

FIG. VIII-2

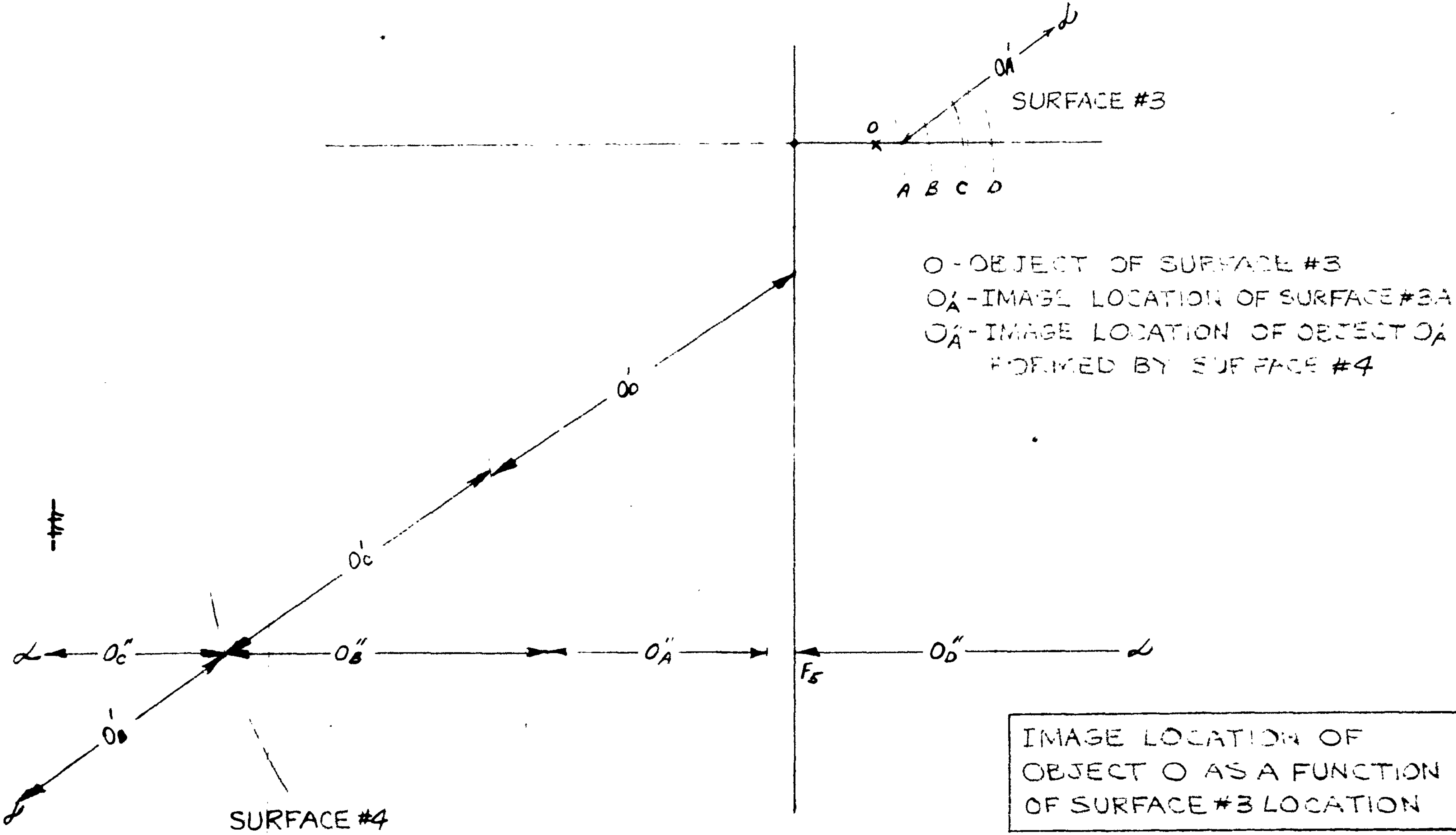
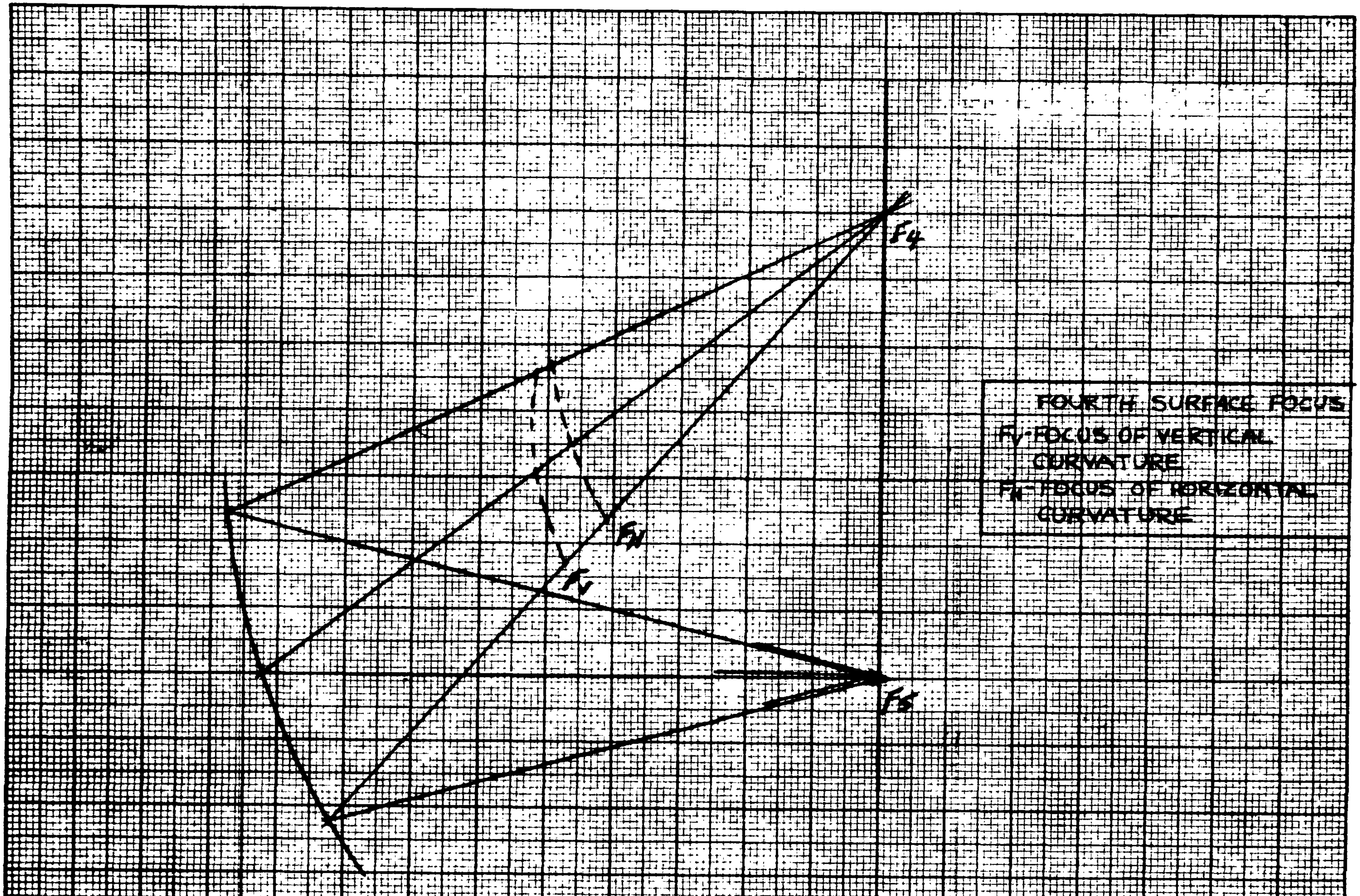


IMAGE LOCATION OF OBJECT O AS A FUNCTION OF SURFACE #3 LOCATION



F_4
F_5
F_H
F_V
FOURTH SURFACE FOCUS
F_V-FOCUS OF VERTICAL CURVATURE
F_H-FOCUS OF HORIZONTAL CURVATURE

FIG. VIII-4

TABLE VIII-2

Image Location of an Object at Infinity with $C_3 = 1.90$

Object at Infinity and		+ 15	0	- 15
Surface 1	Vertical Rays	.59	.58	.52
	Horizontal Rays	.55	.50	.44
Surface 2	Vertical Rays	- .520	- .695	- .830
	Horizontal Rays	- .93	- .83	- .84
Surface 3	Vertical Rays	+ 2.18	+ 5.26	- 21.0
	Horizontal Rays	11.7	13.3	48.3
Surface 4	Vertical Rays	- 2.6	167	2.5
	Horizontal Rays	8.4	7.0	4.5

Table VIII-2 gives the distance from the vertical axis of the images formed by the four surfaces. A location toward the large surface is considered as positive. Looking at the images formed by surface 3, a large variation in location is noted. The image formed by the horizontal ray is located behind the large surface which appears to the eye to be from 4.5 to 8.4 inches in front of the eye. The image formed by the vertical ray is located in front of the fourth surface with the upper portion between the focus and the surface. To the eye, the upper portion would appear to come from behind, while the lower portion would come from 2.5 inches in front. Neither would be able to be brought into focus clearly. Moving the third surface toward the axis to put the upper vertical image at the focus of the fourth surface will result in all parts of the image focusing in front of the eye, but somewhat closer than the present case.

Because of the nature of the image formed by the second surface, it becomes impossible to locate the third surface so that all parts of the resulting image lie on the desired object line of the fourth surface. A certain amount of leeway should be allowable in that the pilot's eye has the capability of focusing on an image formed between infinity and about six inches in front of his eyes. In addition, the depth of field allows the eye to accomodate the vertical and horizontal image when they are close, but not together. The useability of the obtainable image is to be determined when examining the mock-up and prototype units.

IX. MANUFACTURE OF THE UPPER THREE SURFACES

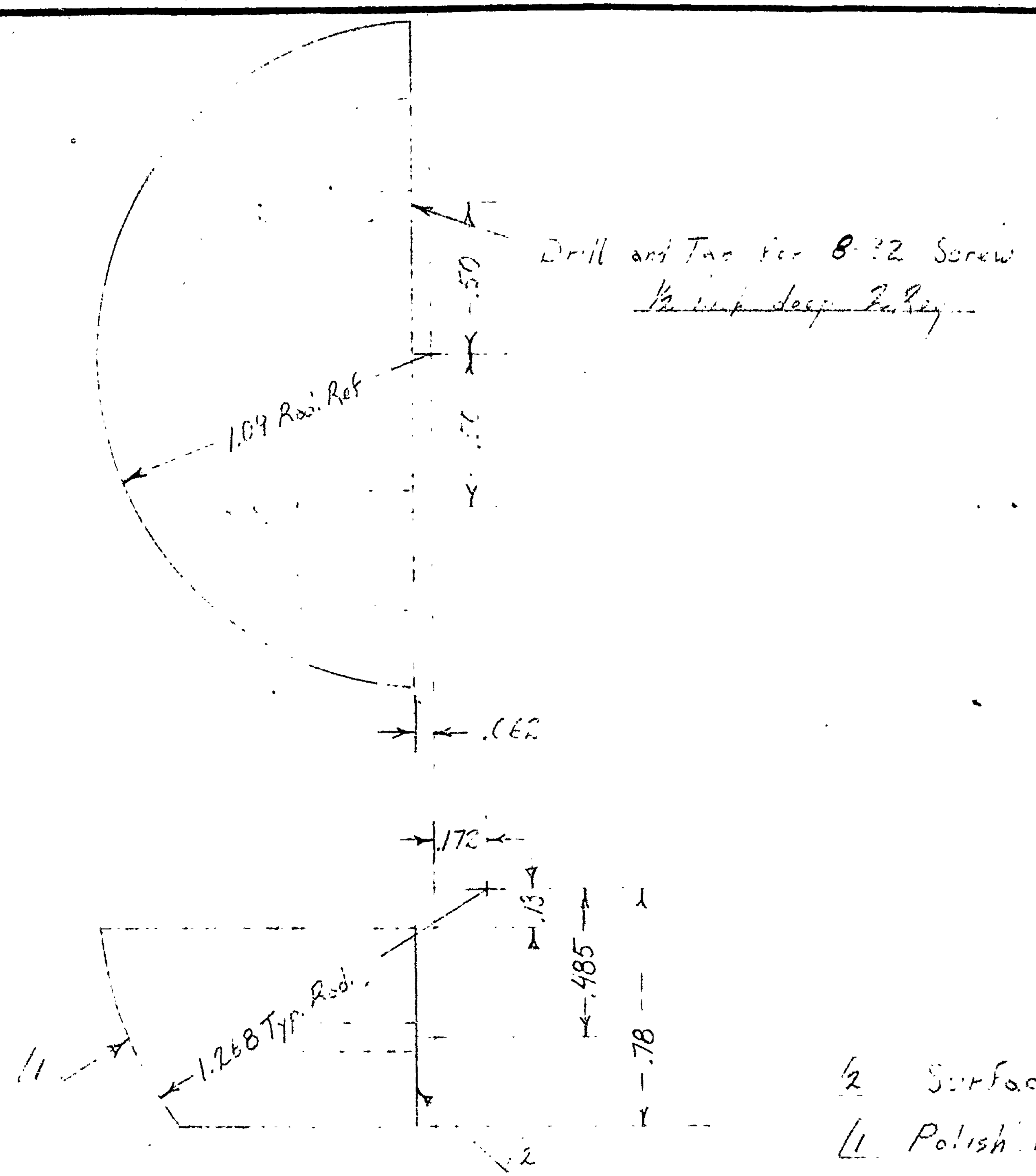
The original proposal called for the manufacture of the four surfaces from blown plexiglas hemispheres. Sections from hemispheres of the proper diameter would be silvered and arranged to approximate the elliptical system. Further ray trace studies as previously outlined showed this to be an unworkable system, as excessive distortion of the view would be obtained unless true ellipsoids of revolution were used. A change from plexiglas to a solid material for the upper surfaces was made. Figures IX-1, 2 and 3 are the drawings of the surfaces required as determined in Appendix A. In the manufacture of the surfaces, a 360° section was initially obtained, which was then cut to form two sections. Allowance was made for the thickness of the mounting plate and mounting holes were located.

Two sets of surfaces were fabricated during the program, one for the mock-up and the other for the prototype. Because of the poor results obtained from the mock-up, a different procedure was followed for the prototype surface fabrication.

A. Mock-up Surfaces

For the smaller upper three surfaces, it was felt better surface control could be obtained, without too great a weight penalty, by machining the surfaces from a solid piece of metal. Table IX-1 gives a list of the more reflective materials and the percent of direct light reflected. As the ray of light is reflected from four surfaces, a reflectivity of 70 percent on each surface would give a final image only 24 percent as bright as the original object. Aluminum, besides having a relative high reflectivity, has the additional advantage of being light weight.

1



		ITEM NO
REQD / UNIT		

UNLESS OTHERWISE SPECIFIED			
DIMENSIONS ARE IN INCHES TOLERANCES ON FRACTIONS ± 1/64	.XX .010	.XXX .005	ANGLES ± 1/2°

DRAWN BY
CHECK
APPD
DESIGN
MFG

DASH NO.	NEXT ASSY	USED ON	NEXT ASSY	FINAL ASSY
	APPLICATION		QTY REQD	

SYM	DESCRIPTION	DATE	APPROVAL

8 [illegible]

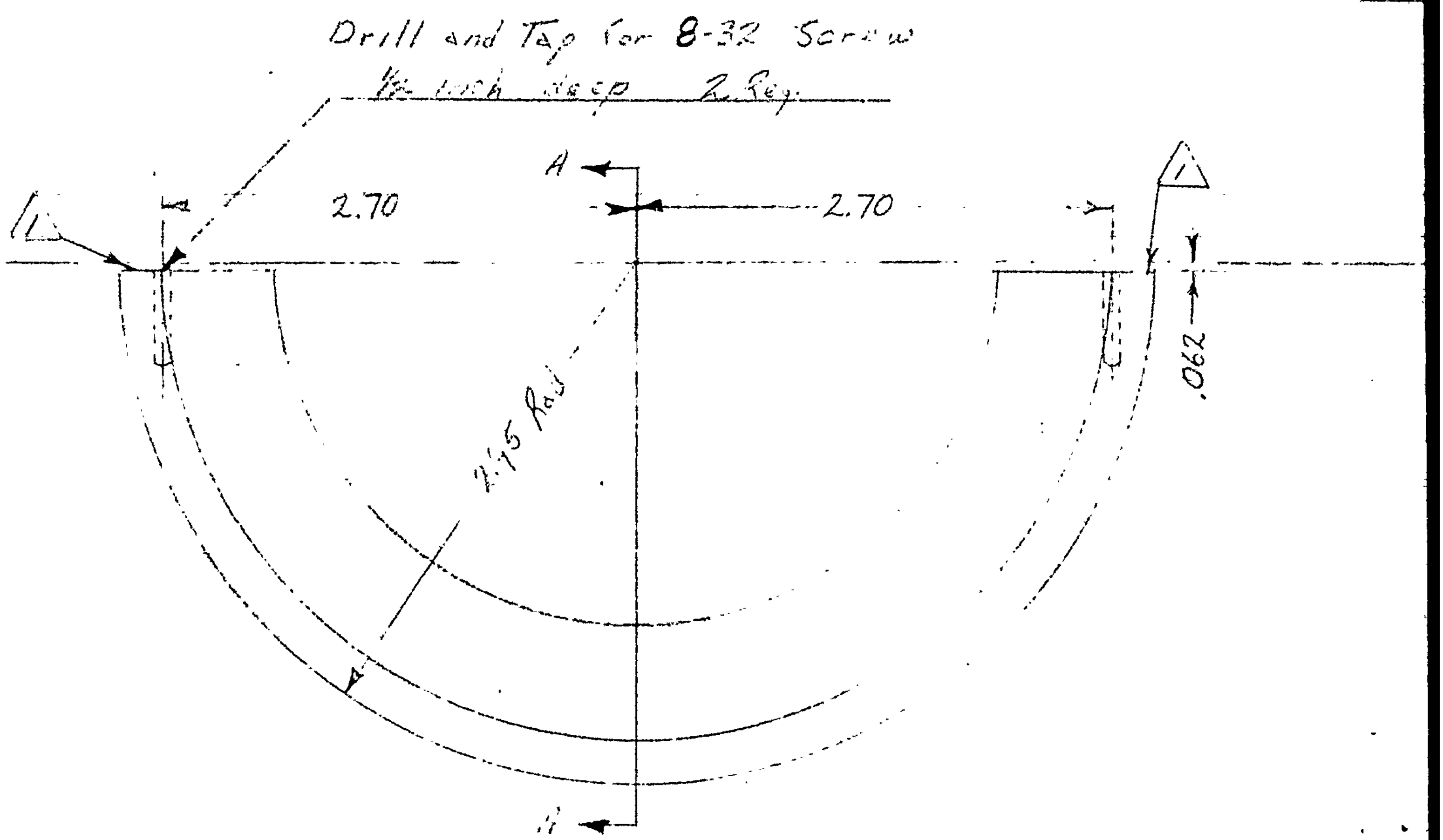
2

3 [illegible] paste [illegible] .001 [illegible]

4 Polish [illegible] mirror [illegible]

		ITEM NO.	PART NUMBER	DESCRIPTION	MATL	MATL SPEC	UNIT WT
REQD/UNIT		LIST OF MATERIAL					

[...]E SPECIFIED .XXX .005 ANGLES $\pm\frac{1}{2}°$	DRAWN BY CHECK APPD DESIGN MFG	FIRST MIRROR PERISCOPE FIG. IX-1	THE OXFORD CORP. 6589 MAIN ST. BUFFALO 21, N.Y.
		SCALE Double	DWG. SIZE B 3041
			CODE SHEET OF



2 POLISH TO A MIRROR FINISH.

1 SURFACE TO BE PARALLEL TO THE CENTERLINE WITHIN .001 INCH/INCH.

1

DASH NO.	NEXT ASSY	USED ON	NEXT ASSY	FINAL ASSY
	APPLICATION		QTY REQD	

ITEM

REQD/UNIT

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
FRACTIONS ± 1/64 .XX .010 .XXX .005 ANGLES ± 1/2°

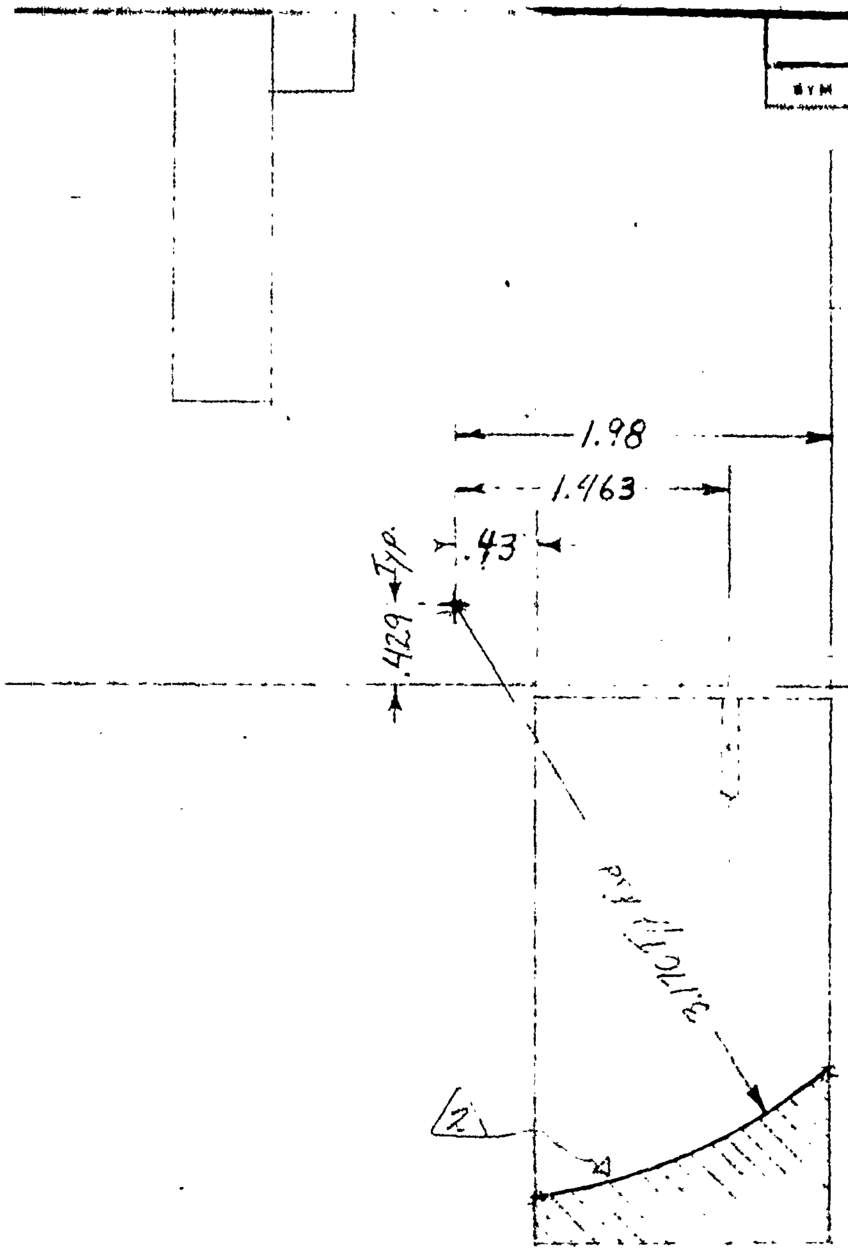
DRAWN BY

CHECK

APPD

DESIGN

MFG



SECTION A-A

2

SYM	DESCRIPTION	DATE	APPROVAL

		ITEM NO	PART NUMBER	DESCRIPTION	MATL	MATL SPEC	UNIT WT
REQD / UNIT							

LIST OF MATERIAL

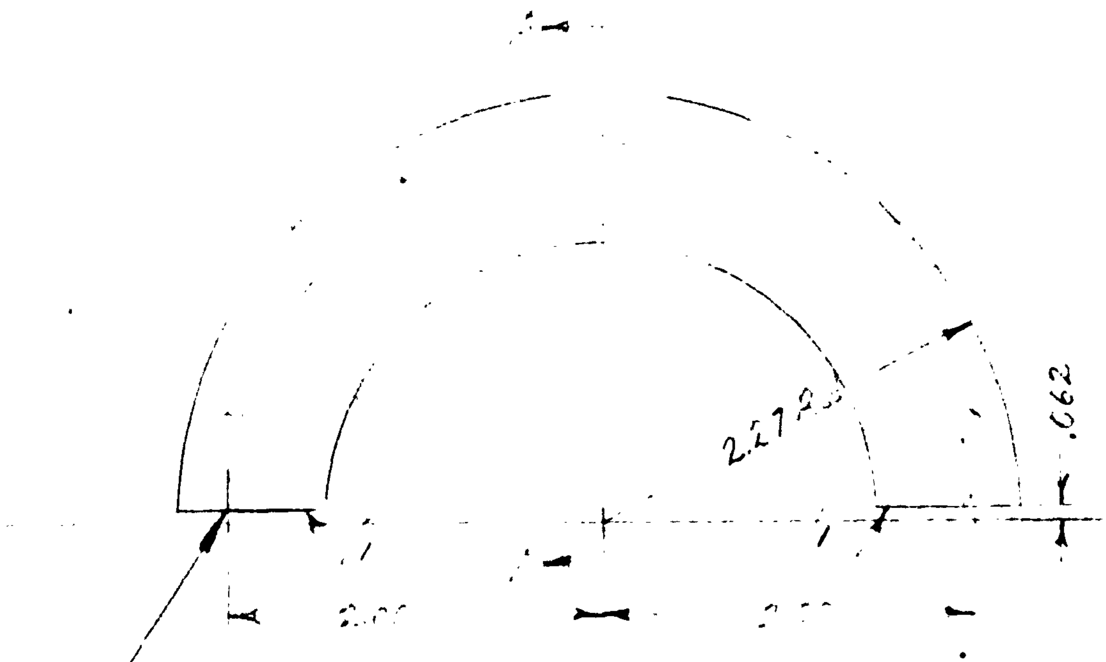
DRAWN BY
CHECK
APPD
DESIGN
MFG

SECOND MIRROR
PERISCOPE
FIG. IX-2

THE OXFORD CORP.
6589 MAIN ST.
BUFFALO 21, N.Y.

DWG SIZE 3 | 3042

SCALE Full | SYSTEM 8a | CODE | SHEET OF



DRILL AND TAP FOR #8-32 SCREW
½ INCH DEEP 3 REQ.

2. POLISH TO A MIRROR FINISH.
1. SURFACE TO BE PARALLEL TO THE CENTERLINE WITHIN .001 INCH/INCH.

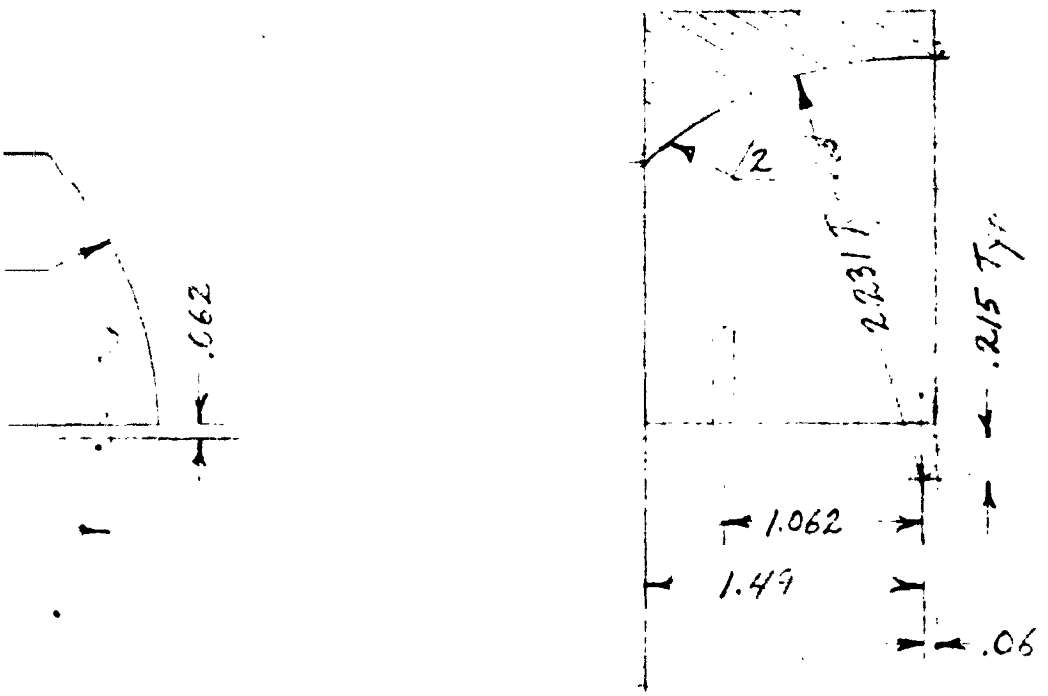
1

			ITEM
REQD/UNIT			

DASH NO.	NEXT ASSY	USED ON	NEXT ASSY	FINAL ASSY
	APPLICATION		QTY REQD	

UNLESS OTHERWISE SPECIFIED				
DIMENSIONS ARE IN INCHES				DRAWN BY
TOLERANCES ON FRACTIONS ± 1/64	.XX .010	.XXX .005	ANGLES ± 1/2°	CHECK
				APPD
				DESIGN
				MFG

SYM	DESCRIPTION	DATE	APPROVAL



Section A-A

2

		ITEM NO.	PART NUMBER	DESCRIPTION	MATL	MATL SPEC	UNIT WT
REQD / UNIT		LIST OF MATERIAL					

ANGLES ± ½°	DRAWN BY CHECK APPD DESIGN MFG	THIRD MIRROR PERISCOPE FIG. IX-3	THE OXFORD CORP. 6589 MAIN ST. BUFFALO 21, N.Y.
			DWG. SIZE B 3043
		SCALE FULL	CODE · SHEET · OF

TABLE IX-1

Material Reflectivity of Normal Incident Light

	Percent Reflectance
Aluminum alloy film on glass	90 - 94
Silver plate	87 - 92
Glass mirror	80 - 90
Aluminum foil	84 - 87
Aluminum alzak specular	75 - 84
Aluminum polished	60 - 72
Rhodium	70 - 90
Tin	68 - 71
Chrome specular	62 - 72
Stainless steel	55 - 65
Nickel	60 - 63
Monel	57 - 62
Aluminum - Mill finish	52 - 55

From a reflectivity standpoint, it was advantageous to use a fairly soft aluminum such as the 1100 or 3003 alloys of Alcoa. The 1100 alloy was used for the smaller surfaces and the 6063 alloy for the second and third surface because of the lack of availability of the 1100 alloy in large rods or bars.

The desired surface curvature was obtained by use of a tracer lathe and a pattern of the elliptical arc. The material was rotated about the vertical axis past the tool, which was positioned by the pattern to follow the desired curve. This resulted in radial tool marks which, although small, had to be removed. In addition, small check marks were noticed, especially in the softer first surface, due to small pieces of metal being torn from the surface.

Following the machining, a hand polishing job was undertaken to remove the tool marks and improve the luster of the surface. Fine machine sewed muslin buffs, motor driven, were loaded with polishing compound and the surfaces to be polished held agains the rotating buff. A white diamond compound was used to remove very fine surface layers, followed by red rouge for polishing. Prior to this, a number of optical compounds were tried on flat aluminum stock without much success. The polishing procedure was a slow one and continually presented the danger of changing the surface curvature due to the uncontrollable hand operation. Difficulty was also encountered in removing the existing marks without making new ones because of the softness of the material. In addition, the luster obtained using the red rouge was not what was hoped for.

This led to consideration of plating the surface with possibly chrome or nickel. After consulting with several plating firms, it was decided to Kanaginize the surfaces. This consists of chemically depositing a layer of nickel alloy approximately .002 inches thick over the surface. It has an advantage over chrome plate, in that it can be applied directly to the aluminum and produces a more uniform coating. It produces a hard surface which can be polished to a bright finish.

Difficulty with the process on the first surface tried, due to its position in the tank, left small pit marks on the surface. The Kanagin was stripped from this surface and subsequently the three surfaces were plated. The result was an initially dull finish which polished to a fairly bright surface with additional buffing with both the white diamond and rouge compound. A fair amount of buffing with the white diamond was necessary to eliminate tool and polish marks present before plating and to remove the dull finish following plating.

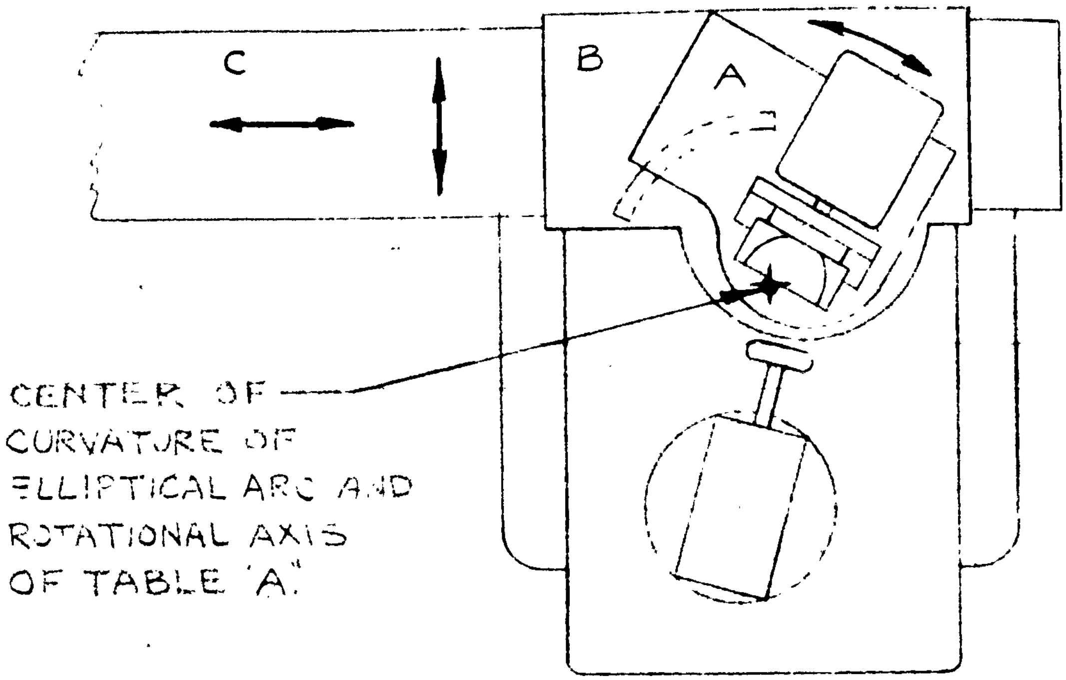
The resulting surfaces, when examined individually, showed a poor micro surface with a number of fairly large waves. This was due to both the initial machining and the subsequent hand polishing. In addition, the micro surface was not as fine as desired.

A check of the machined surfaces was made to determine the actual radius of curvature and the location of the center with respect to the center line of the system and upper edge of the elliptical arc. This was done by looking horizontally into the surface at a number of points on the surface determining the coordinates of the object seen. Using the desired elliptical curve as a reference and determining the angle between the horizontal line at a point and the image seen, a line from that point through the center of curvature could be drawn. The intersection of these lines gives the center of the curvature of the surface. The radius of curvature of the first and second mock-up mirror was good, but the center location was off by several hundredths of an inch. The third mock-up surface was off in both radius and center location by approximately .1".

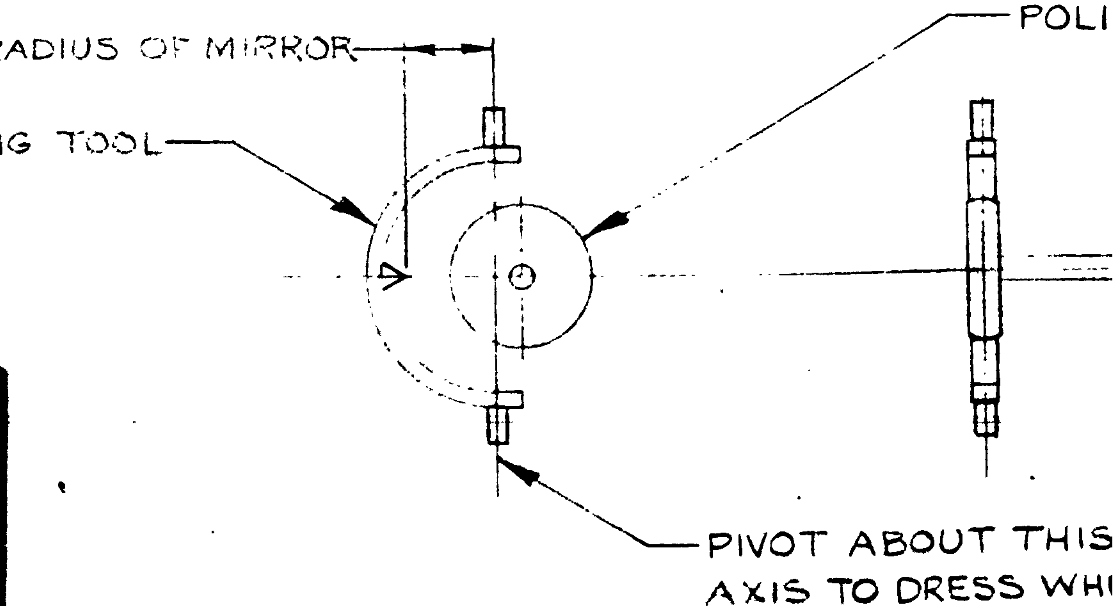
B. Prototype Surfaces

Examining the method of manufacture of the first set of surfaces showed several weaknesses. The first was in the initial machining where radial tool marks were inherent in the method. The second was in the uncontrolled hand polishing required. A method where a random grinding and random machine polishing could be used should reduce the initial mark off and give a more uniform polishing job. In addition, if plating is to be considered, the reflectivity of the basic material is secondary to its machineability.

The possibility of the surfaces being manufactured by an optical house from either glass or metal by their

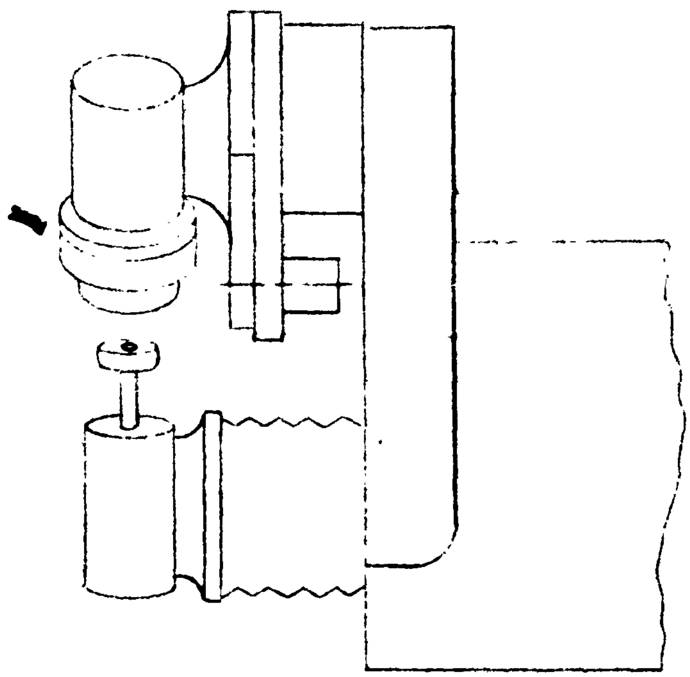


SURFACE GRINDING & POLIS

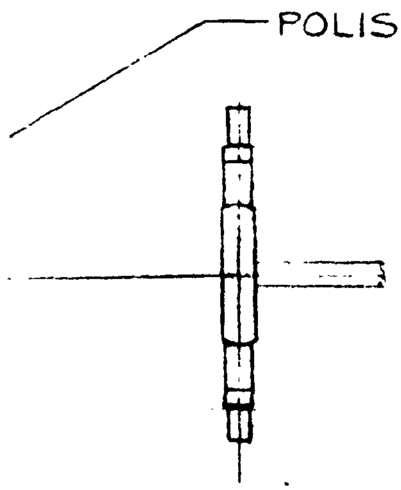


1

WHEEL DRESSING SET-UP



GRINDING & POLISHING SET-UP



OT ABOUT THIS
IS TO DRESS WHEEL

SING SET-UP

2

FIG. IX-4

The following procedure was followed in setting up the machine:

1. The edge of the grinding or polishing wheel was dressed to the desired elliptical radius.

2. The mirror block was placed in the motor and the motor positioned so the center of the elliptical surface (to be in contact with the grinding wheel) was over the center of the pivot point.

3. The height of the grinding motor was set so that the center of the grinding wheel and mirror block were at the same height.

4. Tables "B" and "C" were then moved so that the center of curvature of the edge of the grinding wheel was on the center of the rotating table. In this position, the wheel would touch the surface and a feeler gauge mounted to table "A" and touching the edge of the wheel would not deflect as the table is oscillated about the pivot.

5. The mirror block and the grinding wheel were then rotated in opposite directions and the table was oscillated about its pivot point.

The object to generating the surface in this manner was to obtain a random path for the tool surface contact point. This is done by running the mirror block and grinding wheel at not over three times the oscillating frequency so that the contact point forms a grid like pattern rather than radial lines. The surface then consists of a series of points rather than ridges which have to be leveled by the succeeding operations.

Prior to the grinding of the surface, a review of materials for possible use was made. Table IX-2 lists the machineability of a number of possible materials for screw machine parts. No information was found for grinding specifically. Suppliers of the various metals were contacted to obtain the benefit of any experience they might have on the subject. Based upon recommendations received and material available, three types were chosen and sample flats of each obtained. The three materials, 6063-T5 aluminum, 2024-T4 aluminum and Naval Brass, were ground flat and machine buffed to a fairly bright finish. The brass peice appeared to have a leathery surface with polish marks and a number of deep gouges present. Both aluminum pieces gave similar results with fine polish marks present but without the texture appearance of the brass. While the reflectivity of the brass appeared to be better, the resolution of the aluminum surfaces was superior. Because of the similarity to the 6063-T5 and availability in the required size, 6061-T6 was chosen for the prototype surfaces. It has an advantage over the 2024 in that the finished surface could be chemically brightened if a plating were not used. The more machineable leaded brass was not used because of a poorer finish texture.

TABLE IX-2

Machineability Rating - For Screw Machine

Free cutting brass 61.5 %	200
High Leaded Brass	180
Architectural Bronze	180
Leaded Copper	160
Naval Brass	60
SAE 1112 Steel	100
SAE 1120 Leaded	140
Heat Treating Steel	< 60
Stainless Steel	< 90
Nickel	20
Aluminum 2011 Wrought	Excellent
7075 + 2024	Average
6061 + 6063	Soft

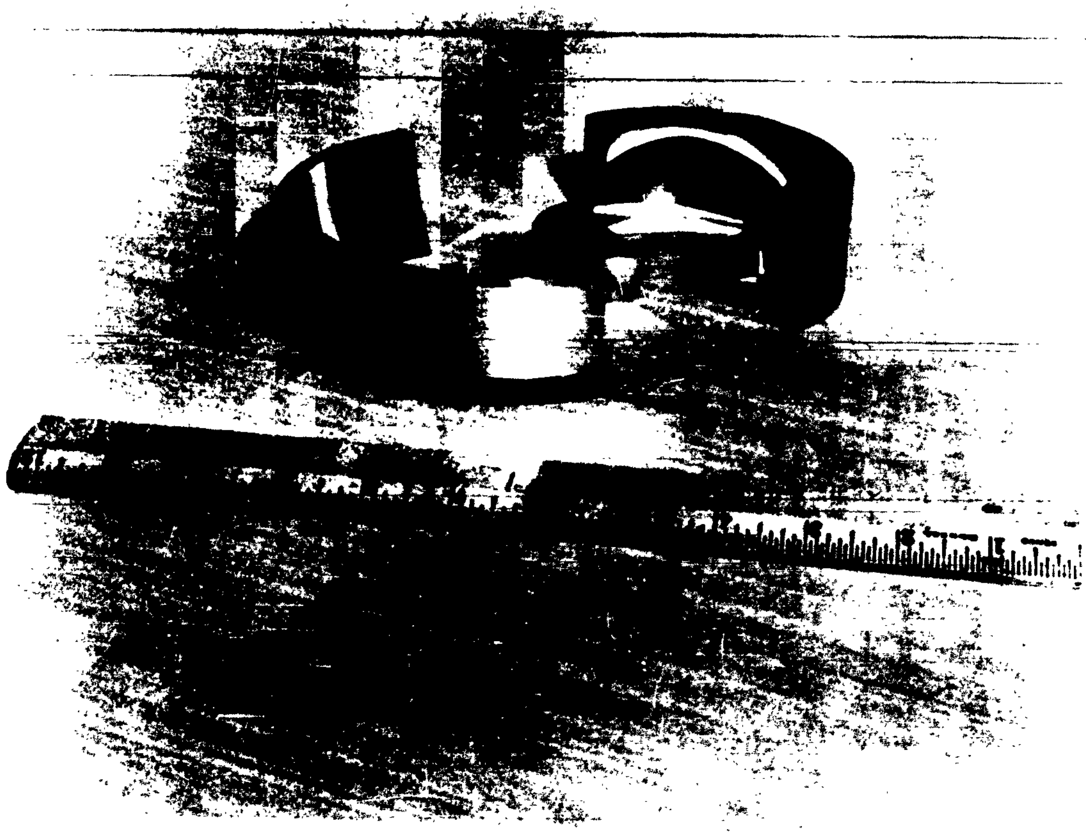
The initial grinding was done with a No. 46 grit wheel with the final two thousandths removed with a No. 150 wheel. It was not possible to grind the surface at low surface and wheel speed, nor to increase the oscillating frequence of table "A" to anything near the wheel speed. This gave a ground surface which was cloudy appearing with some radial mark off. For subsequent polishing operations, the mirror and polishing wheel speed was reduced to about twice that of the oscillation of table "A".

The object of each successive stage of polishing following the grinding operation was to remove enough material to eliminate the mark off of the previous stage, leaving a finer mark off to be removed by the next step. If too large a step were taken, the slower cutting action would greatly extend the time required to obtain the finer pattern. Wheel material, lubrication and pressure also had a large effect on the cutting action of any particular grit. Each time the grit was changed, the wheel was redressed to the proper radius, removing enough material to eliminate any of the previous used grit.

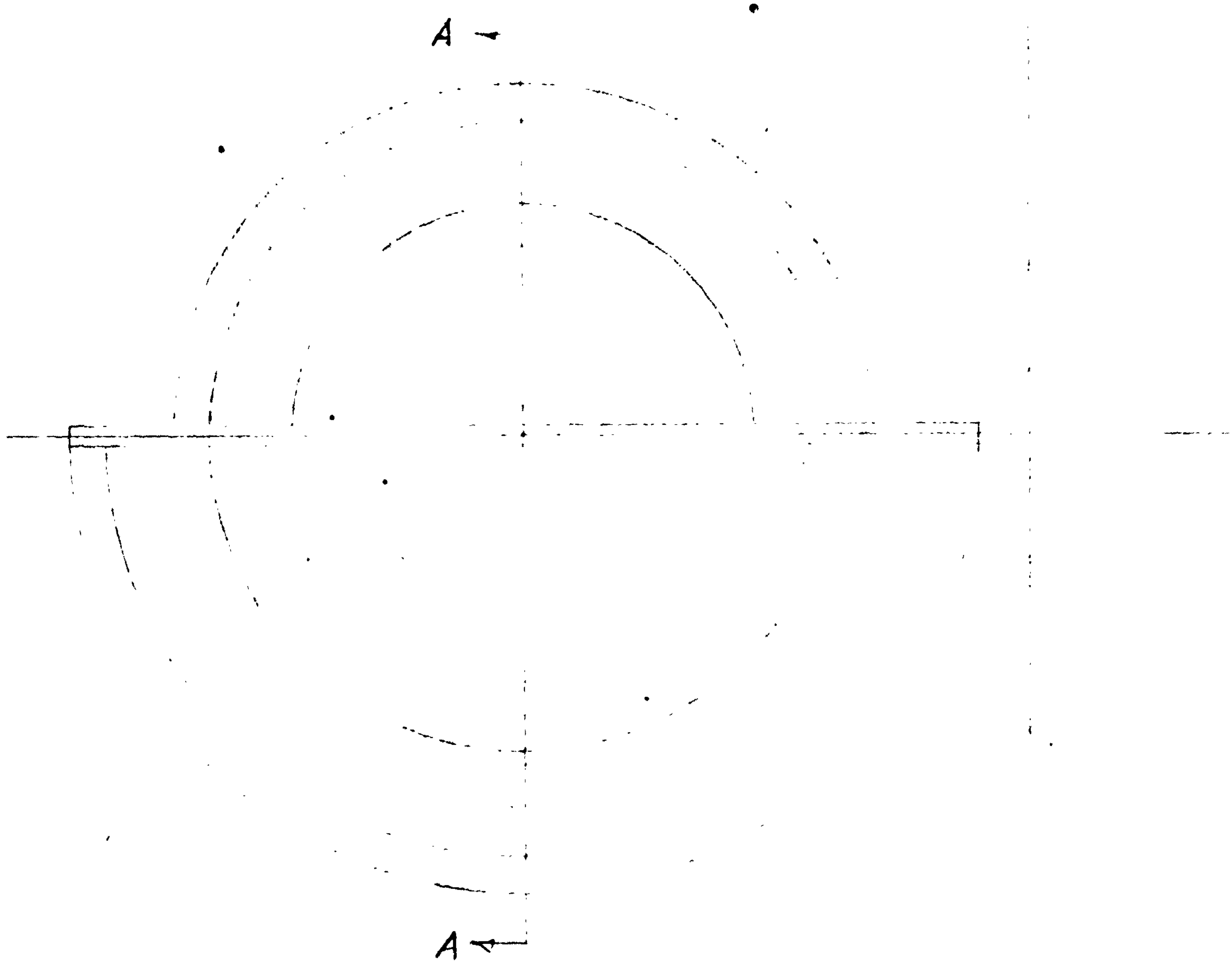
The first grit following the grinding was aluminum oxide No. 120, followed by No. 220, No. 320 and No. 500. Felt, leather and wood were tried for the wheel with water, light and heavy oil being used as a lubricant. Two grades of walrus hide were tried, but found to be too soft to do any cutting, even with the coarse grit. The medium hard felt wheel, on the other hand, caused rapid cutting and heating of the piece. The best operation was obtained using a soft wood wheel with the grit suspended in a light machine oil. Considerable time was spent with each grit and a number of times it was necessary to repeat steps as not all of the deep marks supposed to be removed by that step had been removed. Constant care had to be taken to keep the work area clean so as not to pick up a piece of coarse grit when on a fine finish. Several polishes finer than the 500 grit were used to brighten the surface. Carborundum BFA L1 fine, aluminum oxide grit 125 optical finish powder and Zirconum Oxide No. 49 were used.

In spite of the care and effort put into the surfaces, a point was reached which, while not satisfactory, could not be improved upon. The micro surface was better than the mock-up surface because of the complete machine operation. Some round off of the outer edges of the larger surface was noticed, which could be eliminated by starting with a higher surface and cutting to size, following polishing. It would not be necessary to trim the edges of the first or third surfaces if oversized sections were used. A very fine texture finish was obtained which prevented the reflectivity and the resolution required of the system. It was felt that plating as was done with the mock-up surfaces would give results comparable to the original set which, while better than unplated, would not give the definition required.

The radii and center of curvature locations for the prototype set was much better than the mock-up, although the round off at the edges was more excessive. (See Table IX-1.) The three surfaces unassembled are shown in Figure IX-5. Figure IX-6 is the assembly drawing of the three.



UPPER THREE SURFACES
Fig. IX-5



1

DASH NO.	NEXT ASSY	USED ON	NEXT ASSY	FINAL ASSY
	APPLICATION		QTY REQD	

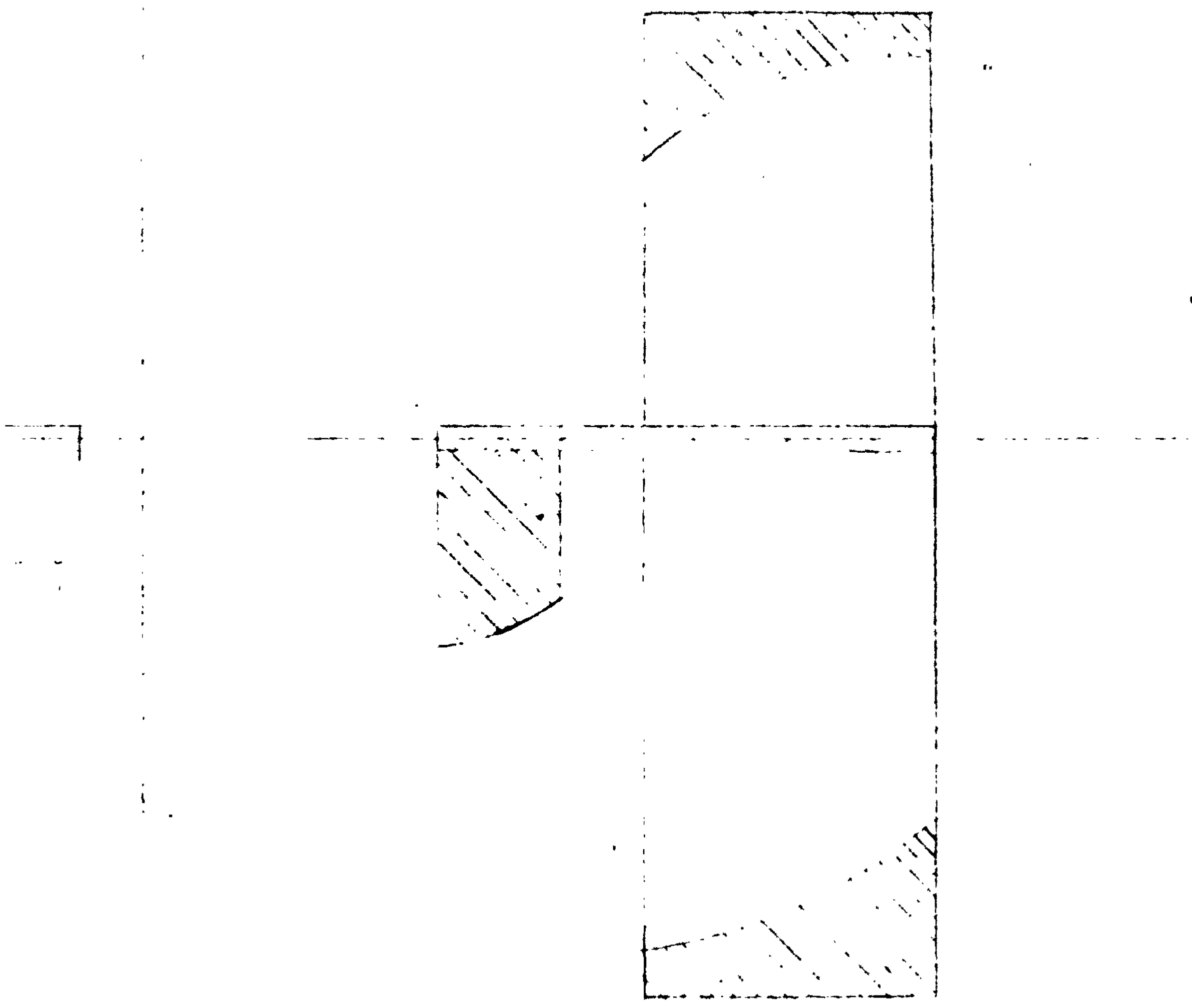
		ITEM NO.
REQD / UNIT		

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON

FRACTIONS	.XX	.XXX	ANGLES
$\pm \frac{1}{64}$	.010	.005	$\pm \frac{1}{2}^{\circ}$

DRAWN BY	
CHECK	
APPD	
DESIGN	
MFG	

SYM	DESCRIPTION	DATE	APPROVAL



2

		ITEM NO.	PART NUMBER	DESCRIPTION	MATL	MATL SPEC	UNIT WT
REQD/UNIT	LIST OF MATERIAL						

E SPECIFIED	DRAWN BY	UPPER MIRROR ASSY PERISCOPE FIG IX-6	THE OXFORD CORP. 6589 MAIN ST. BUFFALO 21, N.Y.
.XXX .005 / ANGLES ± °	CHECK		
	APPD		
	DESIGN		DWG. SIZE
	MFG		
		SCALE F.11	CODE / SHEET OF

Table IX-3

Mirror Radius of Curvature and
Location from the Centerline

		Radius	Location
Surface No. 1	Specification	1.27	.17
	Mock-up	1.27	.19
	Prototype	1.27	.17
Surface No. 2	Specification	3.17	.43
	Mock-up	3.17	.43
	Prototype	3.17	.42
Surface No. 3	Spec. Mock-up	2.23	.19
	Mock-up	2.34	.25
	Spec. Prototype	2.23	.215
	Prototype	2.23	.215

X. MANUFACTURE OF LOWER SURFACE

Because of the size of the fourth surface and the desirability of using a partial silvering to allow visions through the surface, it was decided to stay with Plexiglas as the material. Rohm and Haas Plexiglas G cast sheet was used. It has the property of being light weight and strong with relative freedom from shrinkage and deteriation through long periods of use. It can be formed when heated to a pliable state and can be sawed, drilled or machined like wood when in the solid state.

Ray trace studies indicated the desirability of using an elliptical surface for the large mirror as well as for the three upper surfaces. This presented additional problems, as it would mean the use of a mold with possible mark off of the resulting surface. To avoid unnecessary complication of the manufacture of the mock-up, the use of a spherical section was planned. This would be adequate for the evaluation of the upper surfaces and would allow test evaluation of the effect of a spherical fourth surface.

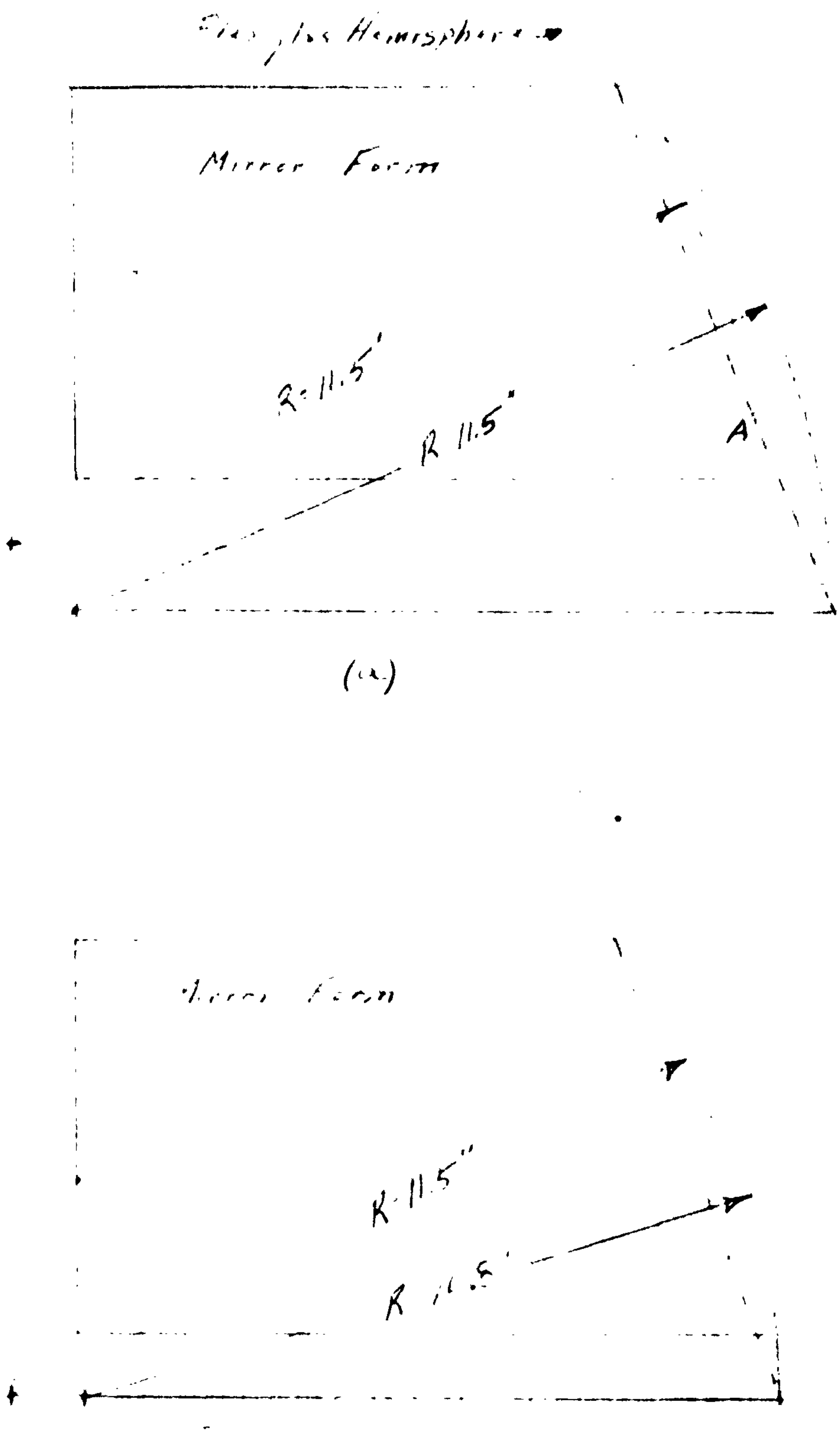
For either configuration of surface, it was desirable to first pressure form a hemisphere from the chosen material. Quarter inch plexiglas, when blown to a hemisphere, would give an average thickness of about 0.12 inches with approximately 0.15 inches at the base and 0.10 inches 30° up from the base. This would give a light weight surface while being thick enough to handle without distorting the surface. To pressure form a hemisphere of 1/4" plexiglas and diameter of approximately 24 inches an oven capable of raising the material temperature to between 290° and 360° F and an air pressure of about 4.5 p.s.i. is required. An oven with this capability had been previously designed and built and was available for the job.

A fixture was designed to which a flat sheet of plexiglas could be clamped and which would withstand a pressure of over 4.5 p.s.i. The size of the hemisphere is controlled by the diameter of the mounting ring and the height to which it is blown. Both under and over blowing the material will give a radius of curvature greater than that of the mounting ring.

To obtain an elliptical surface, it was planned to first blow a hemisphere. After cooling, a pattern of the ellipsoid of revolution for 180° of view would be inserted and the material re-heated. When at temperature, the air pressure would be reduced to allow the material to shrink and form over the patterns. A surface designed for a 10" eye to surface distance would require an 11.5 inch radius of curvature for the elliptical arc. The size of the hemisphere was chosen to require a minimum shrinking to fit the form and no reverse curvature which would require a vacuum.

In Figure X-1a, for example, a hemisphere of 11.5 inch radius, R_s, is shown. Not only is a fair amount of shrinkage necessary, but a vacuum would be required for the plexiglas to fit the form below point A. Figure X-1b shows the result of using a smaller ring and an overblown hemisphere.

A straight line from the upper corner of the pattern to the base of the hemisphere lies inside of the pattern. No reverse curvature and very little shrinkage is required. The base diameter must be large enough to pass the pattern. A base diameter of 10.8 inches was chosen as being optimum. This same base diameter was used for the spherical surface, giving a radius of curvature in the vertical plane of 10.8 inches and a pilot's eye to surface of 9.2 inches. (See Appendix A.)



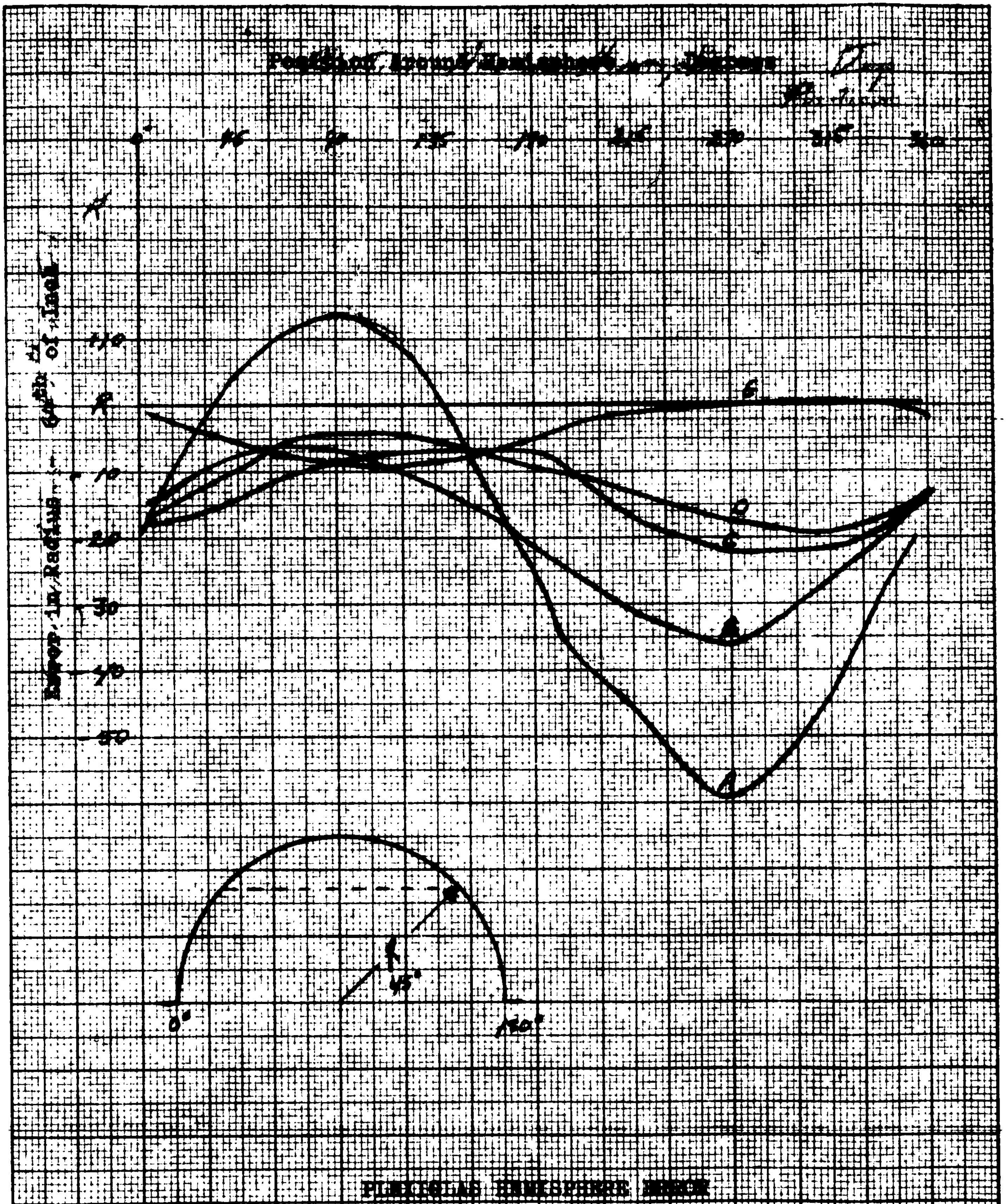
EFFECT OF HEMISPHERE SIZE ON SHRINK FORMING OF FOURTH SURFACE.

FIG X 1

The oven used had the capability of handling a six foot hemisphere and required approximately three and one half hours to bring the glass to temperature. The best results were obtained with the plexiglas stabilized at about 310°F at the start of the blowing process. This was allowed to drop to about 290°F during the ten to fifteen minutes required to bring the bubble to height. A pressure of about 2.5 p.s.i. was required. Continued monitoring of the height was necessary as the hemisphere was allowed to cool. Theoretically, the procedure followed should give a perfect hemisphere, while in practice this has not been the case. Nonuniformity of the original material, slight temperature differences, any slipping of the clamped surface, etc. will cause nonspherical surfaces. Variation in height from the 10.8 inches gives a change in radius of less than one percent for the first two inches height change. This is not serious unless it is due to a change during the cooling process. Because only a quarter of the surface is used for the mirror, it is generally possible to find a section which fits the desired surface very closely.

Three good surfaces were obtained from a total of five hemispheres blown. The radial distance, from the center of the hemisphere at 45° up the side, for the good surfaces averaged .15 inches under the 10.8 inches with a variation of approximately + .15 inches about the average. The variation for the rejected hemisphere were .47 and 1.1 inches. Slippage at the clamping ring was the probable cause for the 1.1 inch error in the one surface. (See Figure X-2.) Sections were chosen to hold the variation for the section to ± .08 inches.

Aluminizing of the surfaces was done in a 48" vacuum chamber by evaporating aluminum onto the surface of the plexiglas. All but one section had the aluminum



PLEXIGLAS HEMISPHERE ERROR

FIG. X-2

applied to the outer or second surface where it could be easily protected with a coat of lacquer. The disadvantage of second surface silvering is that multiple images of lesser intensity are seen along with the main image.

Because of the relatively low intensity of the secondary images, it was felt they would not interfere in the system.

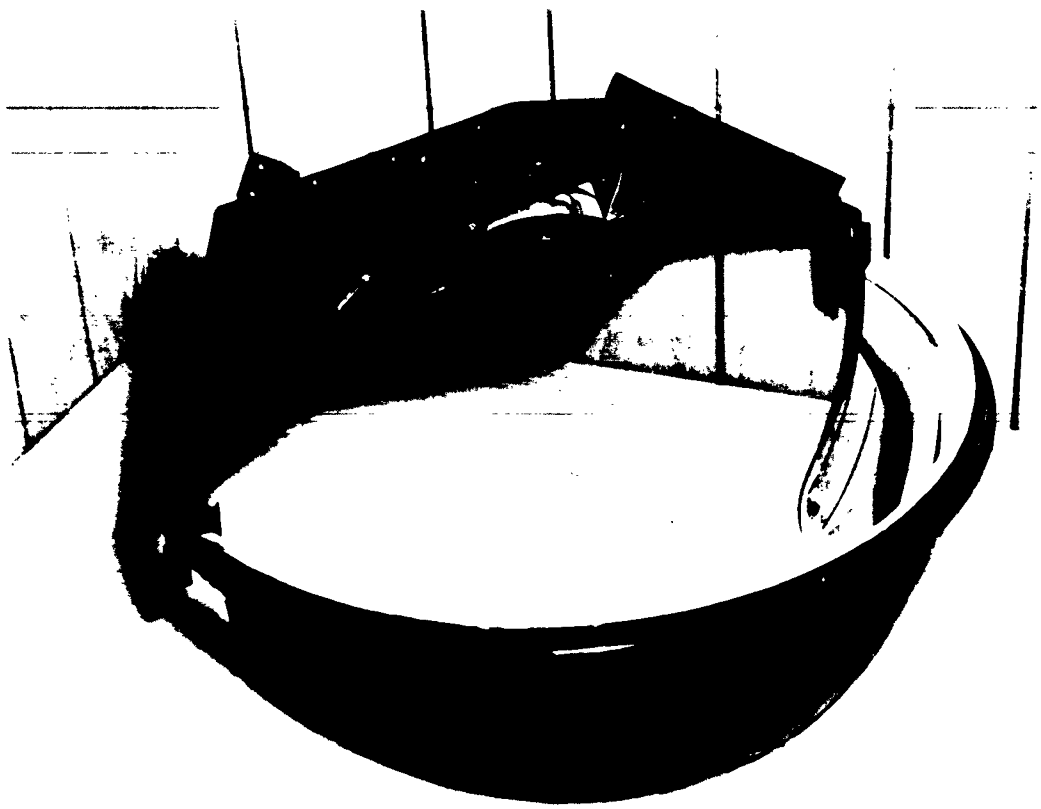
XI. ASSEMBLY AND EVALUATION OF THE PERISCOPE

Following the final polish, the aluminum surfaces were mounted to a vertical plate which had been drilled to match the surface mounting holes and to hold the surfaces in their proper physical relationship. A check of the location was made by observing where the ray crossed the axis and where the images were formed. The assembly to be used in the A3D is shown in Figure XI-1 and XI-2.

With only the upper two surfaces assembled, the rays passed through the predicted axis location and formed an image approximately .7 of an inch from the axis for a horizontal ray. The image of a light source some distance in front of the surface was examined as the light source moved from the 15^{o} down to a 15^{o} up position. With the source in the 15^{o} down position, the image was small, fairly sharp, and located slightly further than .7 inch from the axis. As the source was moved up, a sharp image became unobtainable and its exact location hard to define. For the 15^{o} up position, an image of minimum height was obtained first as the surface on which the image was formed moved from the axis. This was at less than .7 of an inch from the axis, while the location for a minimum width was greater than .7 of an inch. These results agree closely with what was expected and shown in Figure VIII-2.

With the third surface installed, only the position where the ray crossed the axis and could be blocked out was easily determined. The image intensity was too low, due to the size of the image and additional light loss at the third surface, to be able to accurately locate it or make any statements about it. For the prototype surface, the ray crossed the axis as predicted, while crossing at .15 inches lower for the mock-up surface because

A3D PERISCOPE ASSEMBLY – Rear View
Fig. XI–1



A3D PERISCOPE ASSEMBLY – Front View
Fig. XI-2

of the error made in its fabrication. For both systems, the fourth surface was positioned to give a full size undistorted view in the forward direction. Small position changes were required for the two different third surfaces.

With the periscope so assembled, the following observations were made:

1. Illumination

The illumination of the image when using the mock-up surfaces in a normally lit room, was low but sufficient to examine the view. This was greatly improved in a darkened cockpit. An increase of ten to fifteen percent in the reflectivity of each of the surfaces would provide ample illumination for a normal daylight operation. The unplated prototype surfaces were not as good, and while useable when substituted in the mock-up system one at a time, gave a very dim picture when used together. Other than illumination, little difference was noted in the quality of the picture with the prototype surfaces substituted. For this reason, most of the system evaluation was done with the mock-up system.

2. Field of View and Distortion

A field of view of 30° vertically and about 100° horizontally was obtained, with little overall distortion in the presentation, when holding the eye in a fixed position. With slight eye motion, the horizontal view could be shifted to one side or the other from the center position. This was better than expected, as the fourth surface is spherical and therefore optimum for only a forward view. Local distortions were also noted due to surface ripples or imperfections, with double images present for the 15° up view. This distortion was much more serious with the mock-up than with the prototype system.

3. Eye Position Sensitivity

The entire presentation was extremely sensitive to eye position with distortion resulting from small off center motion. Lateral movement caused the picture to rotate and droop to the side opposite the direction of motion and then disappear entirely for a shift in eye position of less than a half inch. Vertical motion, which shifts the imaged eye vertically behind the small surface acting as a window, shifted the vertical view, decreased its range and again causes the disappearance of the image entirely if much over a half inch motion was present. Distortion especially to the sides was introduced by fore and aft motion.

Because of the tight location requirements, it was difficult to locate the proper eye positions, especially when new in the system. With experience, the correct position could be found and held without too much difficulty, as long as this was the only concern of the observer. For use where other distractions are present, or under airplane maneuvers, some positive means of eye location is desirable and can be added to the system. This sensitivity would be greatly reduced if used where space allowed larger surfaces.

While the proper view is being observed by one eye, the second eye being about 2.5 inches off center, is looking out past one of the surfaces. By masking all unnecessary paths, this eye will see nothing and, depending upon the individual, should give no discomfort when left open.

4. Definition and Focus

One of the main objectives to the view seen when using the mock-up periscope, was the poor definition of the image. The prototype surfaces were equally disappointing with little or no improvement in this regard.

While most objects were recognizable, such as brick on a house one hundred feet away, a sharp clear picture could not be obtained with either set of surfaces.

Two factors were present which contribute to this problem. Any texture, tool or polish marks on the surface of the mirrors will tend to smear the image and give a fuzzy appearance. Such marks were present on the surfaces used. The other factor is the location of the image being viewed. An image too close to the eye or one formed behind the pilot's head could not be sharply focused by the eye.

In an attempt to further define the problem, additional visual checks were made with the system. The position of the object of the fourth surface depends upon the third surface location. This can be changed by vertical or fore and aft motion of the surface. While moving from the design positions will change the ellipsoid and the system symmetry, small changes necessary to examine the effect on focus will not seriously distort the view directly ahead. For each position of the third surface, a slight change in the position of the fourth surface was necessary to reposition the imaged eye to the proper location. This was determined by finding the position for a full size undistorted view.

With the third surface moved slightly from its initial position, the view was examined both for overall sharpness as well as for local improvement in definition. Because the vertical and horizontal image of low objects formed by the second surface was very close to the same point, it was felt this area could be more easily focused than other parts of the image. As a result, the optimum position for the third surface was found to be up approximately .1 inch from the design position. This essentially moves the surface out from the image and decreases the distance between the foci of the resulting elliptical surface. With the surface in this position, the sharpness or lack of it was uniform throughout. No position checked gave an image that was much better in one section than any other. A movement of greater than .1 inch from this position gave a very blurred view. At best, the sharpness left much to be desired. The fact that the definition was uniform throughout the image is an indication that the surface quality rather than image location was the main cause of the problem.

Another difficulty was noticed during the observations resulting from the image location. Excessive eye strain was experienced after a few minutes of viewing, with nausea developing from prolonged observation. This was due to the strain of focusing on an image too close to the eye. By moving the eye to a position six to eight inches behind the axis and moving the large surface toward the axis to better relocate the imaged eye, a view of approximately .4 size was obtained. This view, because of the small size, was fairly sharp and because of the increased eye to image distance, could be observed with little or no eye strain.

XII. RESULTS AND CONCLUSIONS

The overall result of the analytical studies and evaluation of the manufactured periscope did not meet with early expectations. Several problems were encountered, both in the system and in the manufacture of the surfaces which led to the recommendation to discontinue the development effort.

From the viewpoint of illumination, overall distortion and field of view, the system was either satisfactory or could be improved upon with a little additional effort. The same cannot be said for the eye sensitivity, poor focus and definition problems encountered.

The extreme sensitivity to eye location and the inability of the system to form a full image at the desired distance from the eye is inherent with the small size of the system required for this application. A positive means of positioning the eye could be incorporated and would be necessary for rapid image location. It would still be necessary for the pilot to hold his head steady in the proper position. While not explored to any extent, the addition of a suitable lens could be the answer to the focus problem.

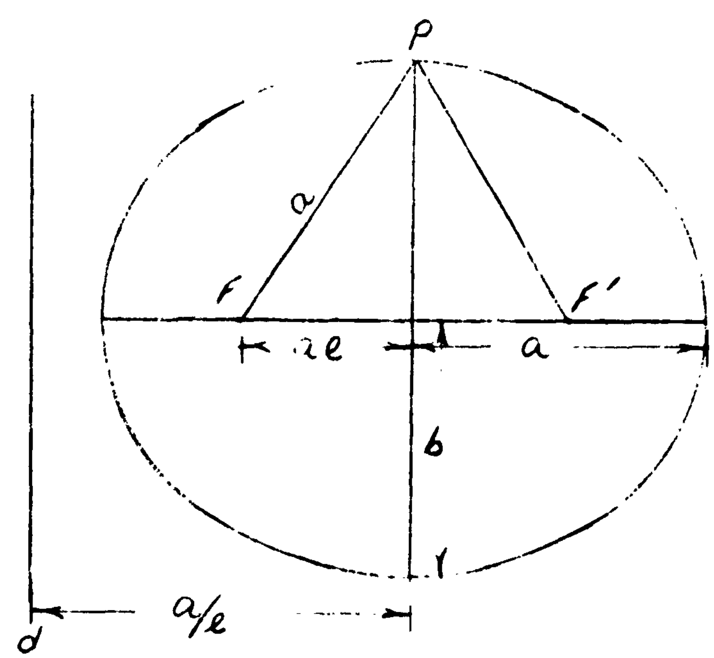
Poor definition of the image due to unsatisfactory surface quality is probably the main obstacle to overcome. Considerable effort, as previously outlined in the report, brought unacceptable results. It is felt that more sophisticated optical fabrication techniques beyond the capability of this contractor are required in the grinding and polishing of the surfaces.

When considering the optical fabrication problem together with the other major problems, the advisability of further pursuit of the development was questioned by the contractor. As a result of these findings, the Bureau of Naval Weapons concurred in the contractor's recommendation that further development effort be discontinued.

APPENDIX A

Construction of the Elliptical Arc

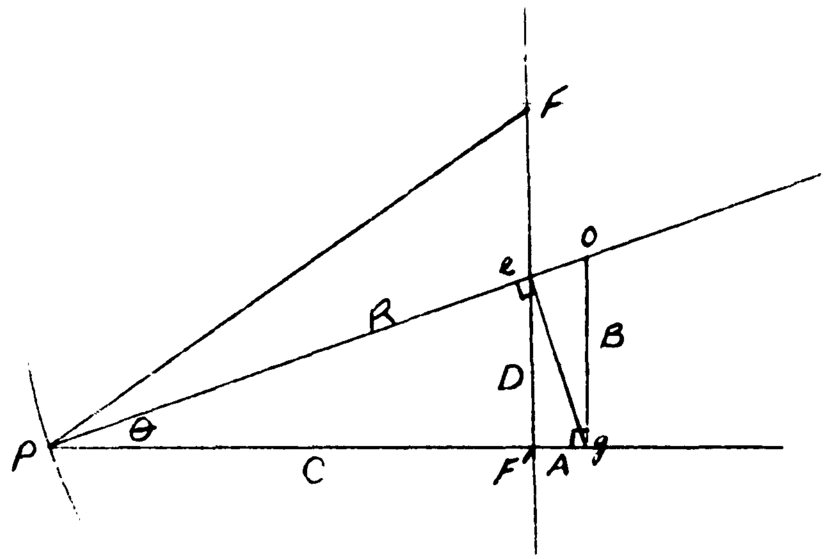
An ellipse is defined as the locus of a point P which moves so that its distance from a fixed point F or focus bears a constant ratio $e<1$ to its distance from a fixed straight line or directrix. Its major axis = 2a and minor axis = 2b and has two foci F and F'. An elliptical surface has the property that a ray to any point on the surface through one focus will be reflected through the other focus.



The Ellipse

Figure A-1

For use in the periscope, only a portion of the ellipse will be used. Any small section may be very closely approximated by a circular arc whose center is found as shown in Figure A-2.



Circular Approximation for Elliptical Section

Figure A-2

Bisect the angle formed by connecting a point on the surface P to the two foci. The center of the circle will lie on this line, so as to have the same slope at P as the ellipse. At the point e where the angle bisector meets the major axis, draw a perpendicular to the bisector which meets the line from P to one focus at point g. A perpendicular to line P F' at a point g will intersect the bisector at the center of the circle.

From the diagram, it follows

$$B = (C + A) \tan \theta$$

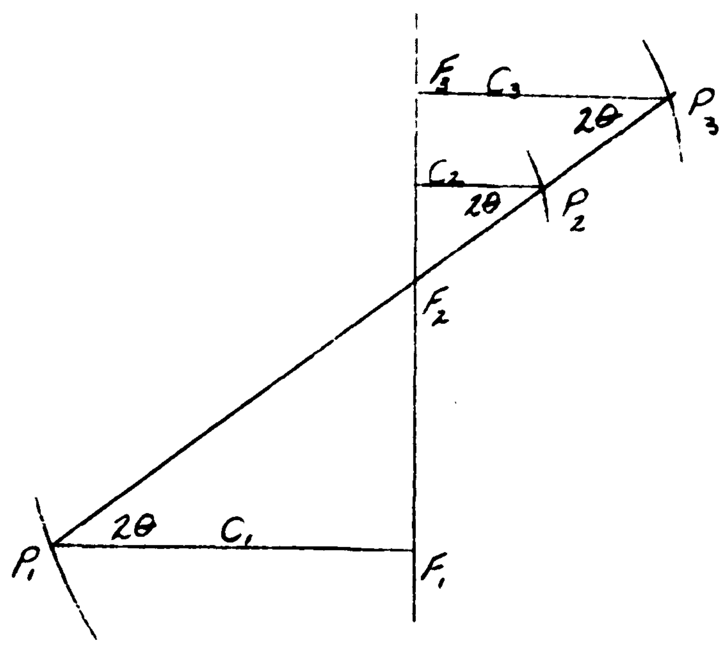
$$R = \frac{C + A}{\cos \theta}$$

$$A = C (\tan \theta)^2$$

$$2 \theta = \tan^{-1} \frac{F - F'}{C}$$

In general, the distance F - F' and C will be assigned which will then fix the location of O, the center of the circle, and the radius of curvature.

The periscope uses two sets of two surfaces, each with the eccentricity of the two surfaces in a set equal. Having determined one surface only, the scale of the second must be determined. (See Figure A-3.)



Surfaces with the same Eccentricity
Figure A-3

As the triangles formed by the major axis and a ray from the foci to points P_1 and P_2 or P_3 are similar, knowing one and one element of the second, completely defines the second.

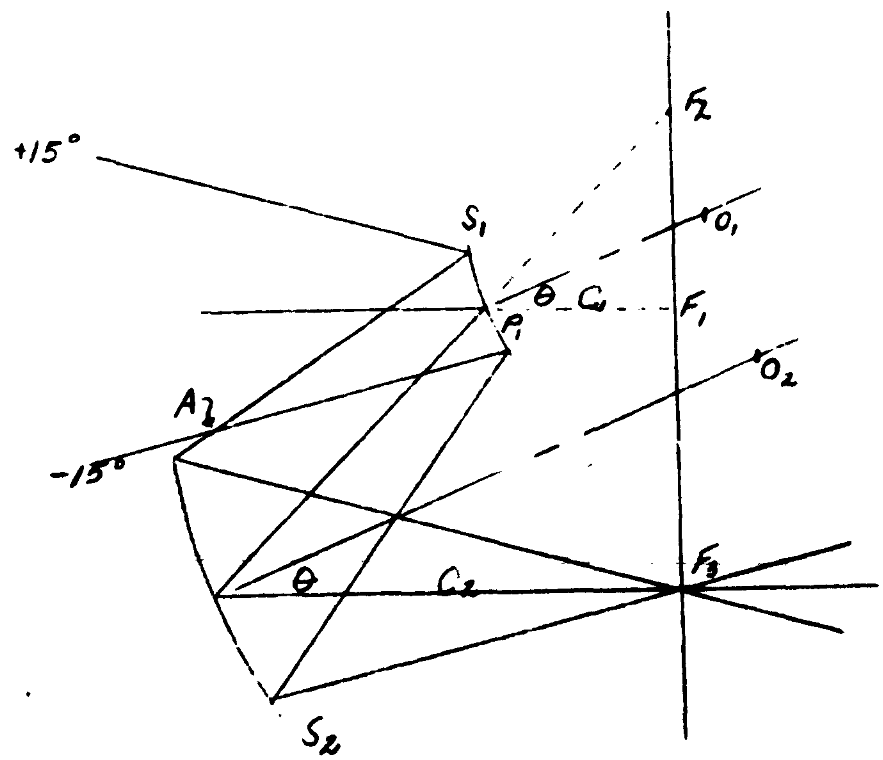
Construction of the Periscope Sections

Using the equations of the previous sections, the four surfaces of the periscope are determined as follows:

1. Choose values to be used for C_1 and the distance between foci $F_1 - F_2$. This determines the center of curvature location O_1 and the radius of curvature of the surface S_1. (See Figure A-4.)

2. Draw the incoming $\pm$ 15° up rays and the reflected + 15° ray from S_1. The second surface is to have the same eccentricity as S_1 and be located beyond point A the intersection of the reflected + 15° ray and the incoming - 15° ray so as not to block the - 15° ray.

3. Choose C_2 to put the surface S_2 beyond point A. This and the value θ of S_1 determines the location of O_2 and the curvature of S_2.



Location of Second Surface

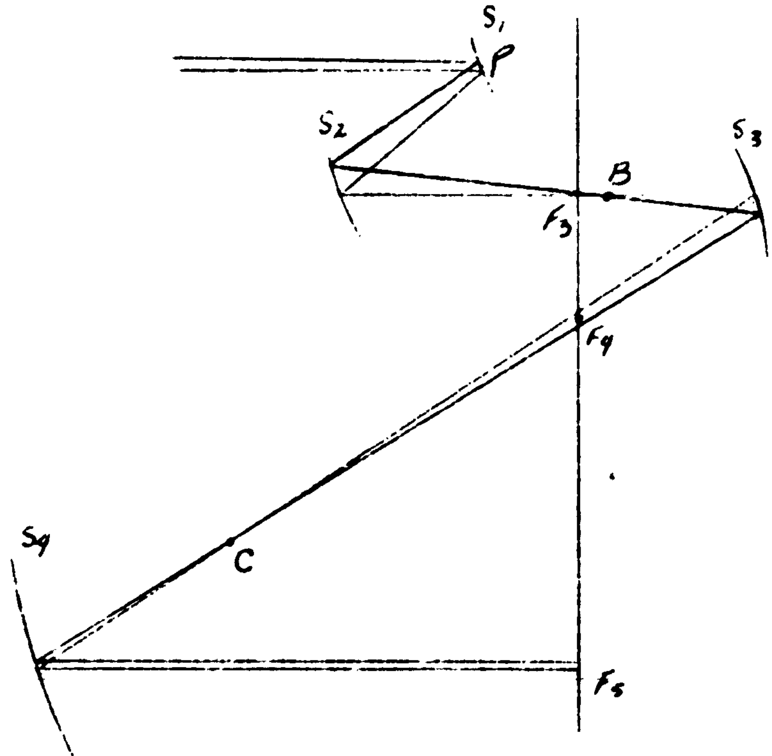
Figure A-4

4. Surface S_4 is determined by the values of R_4 and distance between foci, chosen to fit the cockpit configuration. This then determines the eccentricity but not the scale of S_3. $\frac{C_3}{C_4} = \frac{F_3 - F_4}{F_4 - F_5}$

5. Determine where two horizontal rays into S_1 just above and below point P will be focused by S_2. (Figure A-5, point B.) This then becomes the object location for S_3.

6. Determine where two horizontal rays into S_4 just above and below the eye will be focused by S_4. (Figure A-5, point C.) This then becomes the point where S_3 must image the incoming rays.

7. Determine C_3 experimentally to accomplish item 3.



Location of Third Surface

Figure A-5

The following are the calculations defining the surfaces as manufactured for the prototype system.

Surface No. 1

Let $F_1 - F_2 = 1''$

$C_1 = 1''$

$\therefore\ \theta_1 = .5 \times 45^\circ = 22.5^\circ$

$A_1 = C\ (\tan\ \theta_1)^2 = (.4142)^2 = .172$

$B_1 = (C + A)\ \tan\ \theta_1 = 1.172 \times .4142 = .485$

$R_1 = \dfrac{C + A}{\text{Cos}\ \theta_1} = \dfrac{1.172}{.9239} = 1.268$

Surface No. 2

Let $C_2 = 2.5''$

$\theta_2 = 22.5^\circ$ (to keep slope $\therefore$ eccentricity same as No. 1 surface)

$\therefore\ A_2 = C_2\ (\tan\ \theta_2)^2 = 2.5\ (.4142)^2 = .429$

$B_2 = (C_2 + A_2)\ \tan\ \theta_2 = 2.929 \times .4142 = 1.213$

$R_2 = \dfrac{C_2 + A_2}{\text{Cos}\ \theta_2} = \dfrac{2.929}{.9239} = 3.170$

$F_2 - F_3 = C_2 = 2.5''$

Surface No. 4

Let $R_4 = 10.8$

$\theta_4 = 18.6^\circ$ (value to give $F - F \approx 7''$ with $R_4 = 10.8$)

$\therefore\ R_4 = \dfrac{C_4 + A_4}{\text{Cos}\ \theta_4} = \dfrac{C_4 + C_4\ (\tan\ \theta_4)^2}{\text{Cos}\ \theta_4}$

$C_4 = \dfrac{R_4\ \ \text{Cos}\ \theta_4}{1 + (\tan\ \theta_4)^2} = \dfrac{10.8 \times .9478}{1 + (.3365)^2} = 9.203$

$A_4 = C_4\ (\tan\ \theta_4)^2 = 9.203 \times .113 = 1.040$

$B_4 = (C_4 + A_4)\ \tan\ \theta_4 = (9.203 + 1.040)\ (.3365) = 3.445$

$F_4 - F_5 = C_4\ (\tan\ \theta_4)^2 = 9.203 \times .759 = 6.995$

Surface No. 3

Let $\theta_3 = 18.6^\circ$

Determine graphically or mathematically, the size of the surface to focus the object at the desired point.

For $C_3 = 1.90''$

$A_3 = C_3\ (\tan\ 18.6^\circ)^2 = 1.90\ (.3365)^2 = .2147$

$B_3 = (C_3 + A_3)\ (\tan\ 18.6^\circ) = (1.90 + .2147)\ (.3365) = .7117$

$R_3 = \dfrac{C_3 + A_3}{\text{Cos}\ 18.6^\circ} = \dfrac{1.90 + .2147}{.9478} = 2.231$

$F_3 - F_4 = C_3\ \tan\ 37.2^\circ = 1.90 \times .759 = 1.442$

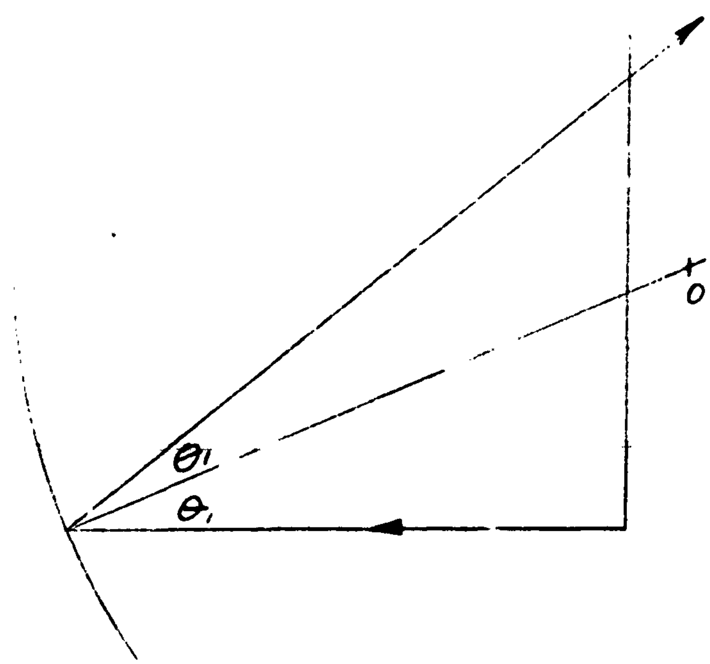
APPENDIX B

Graphical Ray Traces

As in most optical systems, it is necessary to make ray traces in order to understand the system and to investigate different configurations. In some cases, the ray being traced remained in one vertical plane requiring a two dimensional plot, while in others, a three dimensional plot was necessary.

A. Two Dimensional

The ideal periscope system considered consists of elliptical surfaces rotated about the vertical axis containing the foci of the surfaces. Vertical sections through the axis will also contain the centers of curvature of the arcs of the intersection of the plane and surfaces. Any ray entering the system in such a plane can be traced through the system on a two dimensional plot. The arcs are sections of circles with their centers known and the angle of incidence equals the angle of reflection. (See Figure B-1.) A top view of such a system would show the ray and its reflections to be co-linear.



Two Dimensional Ray Trace

Figure B-1

B. Three Dimensional

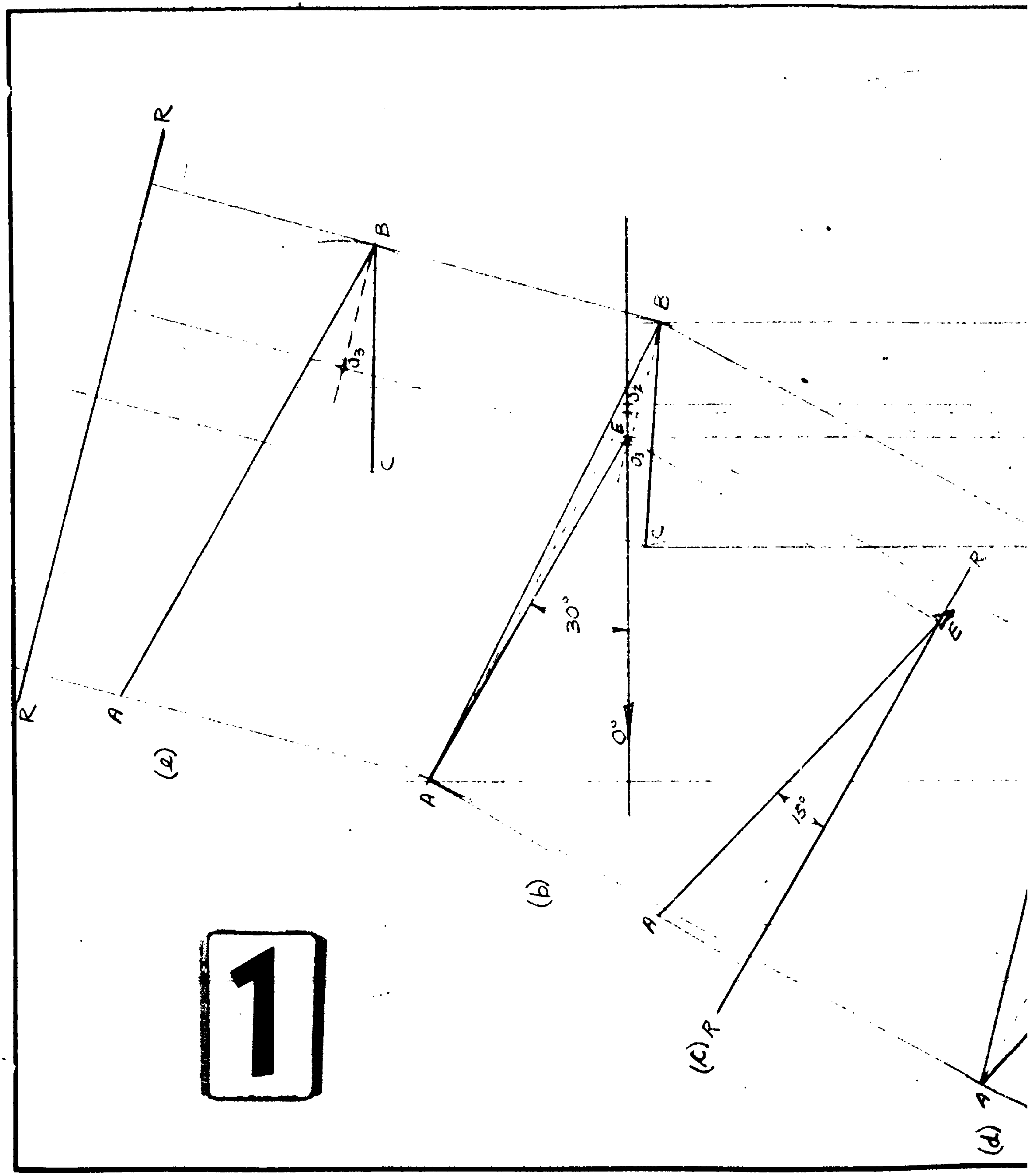
For several of the cases considered, the incoming ray was not in a vertical plane containing the centers of horizontal and vertical curvature of the surface. It then becomes necessary to use a three dimensional descriptive geometry analysis, as the reflected ray doesn't lie in the same vertical planes as the incoming ray.

For any point on the surface of the mirror, the curvature of the arc, formed by cutting the surface with a horizontal plane or vertical plane through the center of the elliptical arc, is known. It then becomes necessary to break an incident ray into components in these planes, in order to determine the direction of the reflection. An example of this is given in Figure B-2.

View (a) is the profile view of the system with the elliptical arcs and their centers located. For this example, the surfaces are to be formed by rotating the arcs about a vertical line through the centers of each of the arcs. Thus the centers do not lie along a common vertical axis. The ray path shown is the projection of the ray on this vertical plane.

View (b) is the top view of the system with the centers of the arcs located along the fore and aft axis of the system. The ray to be traced through the lower two surfaces is shown leaving the eye position E at a 30° angle from the forward directions. The ray chosen is also to have a vertical angle of 15°. This angle appears as a 15° in a vertical plane containing the ray shown in view (c). The location of point A, or the point where the ray intersects the surface, is determined by finding a point on the ray path that satisfies the following conditions, in the following manner:

1. Assume a location for point A in view (c). This determines the location in view (b) and the vertical distance of A above the base line R-R.



1
(a)
(b)
(c)
(d)
30°
0°
15°

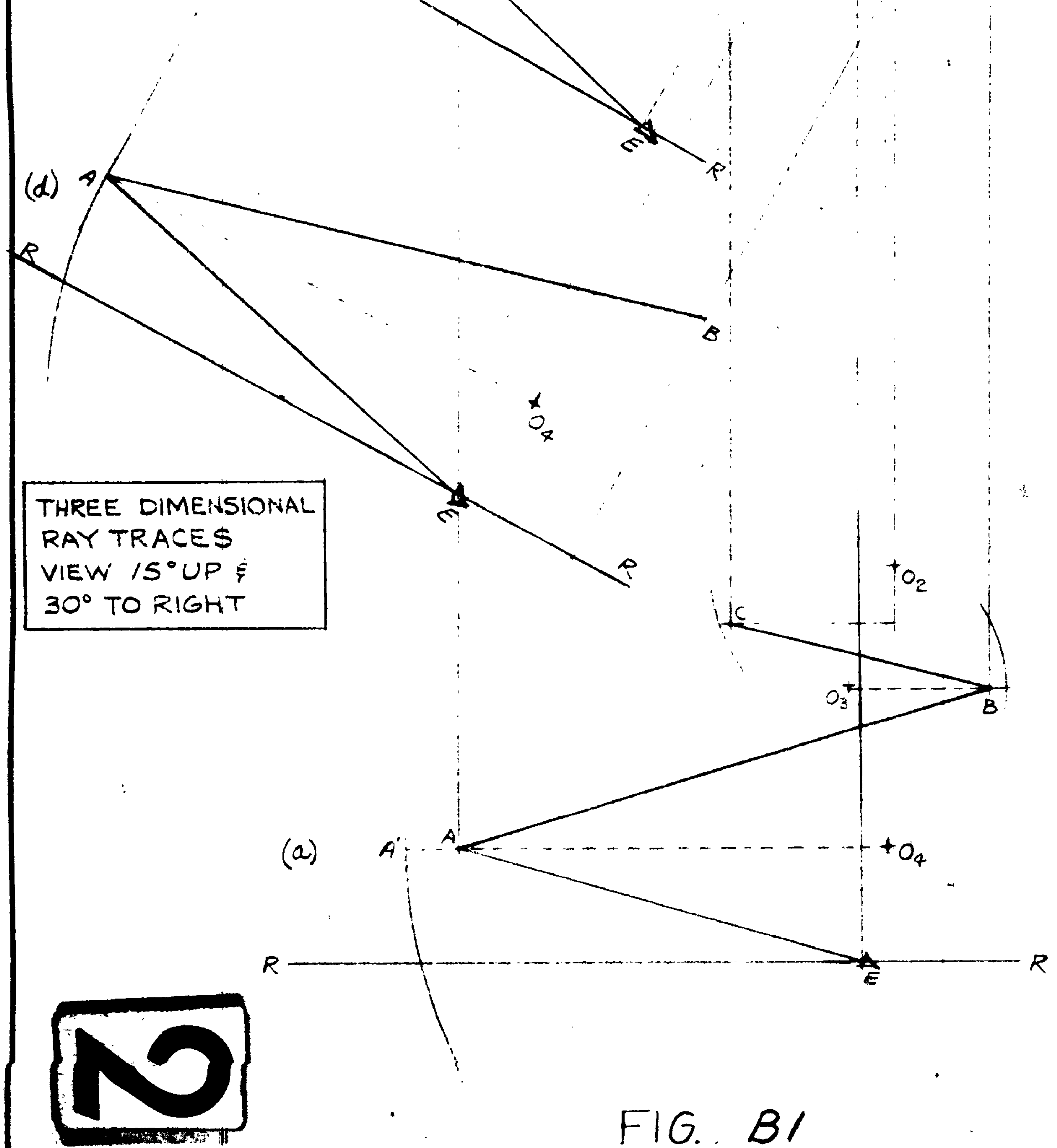

THREE DIMENSIONAL
RAY TRACES
VIEW 15° UP &
30° TO RIGHT
(d)
A
B
E
R
O4
(a)
A'
A
B
C
O2
O3
O4
E
R
2

FIG. B1

2. Determine, using view (a), the radius of the arc formed by the intersection of the surface with the horizontal plane containing point A.

3. Using the center of the arc O_4 in view (b) and the radius determined in step two, draw the top view of the arc. It must intersect ray A-E at point A if point A is on the surface.

Locating point A fully describes the incident ray to surface No. 4. The reflection in a horizontal direction is found in view (b) by setting the angle of reflection equal to the angle of incidence. A vertical plane through point A and O_4 is chosen as the intersection of the surface and this plane is the same as shown in view (a). The projection of ray E-A is shown in view (d) along with C_4 the center of curvature of the arc. The vertical distance of these points from R-R is taken from view (a). Again setting the angle of reflection equal to the angle of incidence, the projection of the reflected ray may be found. Point B, the intersection of this ray with the third surface, is determined in the same manner as was point A. This procedure is followed until the ray being followed leaves the top surface.